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AGRICULTURAL FIRE USE IN THE BRAZILIAN AMAZON: SOME EVIDENCES FOR THE STATE OF PARÁ REGARDING THE ECONOMICS OF ACCIDENTAL FIRES AND FALLOW MANAGEMENT

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"…the practice of mutual aid and its successive developments have created the very conditions of society life in which man was enabled to develop his arts, knowledge and intelligence …the periods when institutions based on the mutual-aid tendency took their greatest development were also the periods of the greatest progress in arts, industry, and science."

Piotr Kropotkin, Mutual Aid, a Factor of Evolution

ABSTRACT

The use of fire as an agricultural tool perpetuates in Brazilian Amazon, despite its negative socioeconomic, environmental and public health impacts. Two topics of the problem are investigated, by looking to the current period (2009-2010) and for three municipalities of the State of Pará, namely Santarém, Belterra and Paragominas. The analysis is restricted to motivations and consequences with strictly economic nature and fires linked with deforestation are kept out of the scope of analysis.

Slash and Burn Agriculture (S&BA) is practiced by smallholders mainly for growing annual crops. The first essay demonstrates that the profitability of S&BA is governed by the trade-off between cost-free fertilization through the burning of secondary vegetation and idleness of the land. Additionally, it is established that, a reduction of the fallow duration, depending on the initial duration, can generate a cash surplus that can be used to finance (at least partially) the transition to a fire-free agriculture.

The second topic addressed is the one of accidental fires, conceived as a phenomemon that emerges from collective behavior.

The second essay tests the hypothesis that eventual damage to assets belonging to other farmers is not internalized by farmers when they decide to start a fire. Such hypothesis is not refuted by georeferenced data for the municipality of Paragominas and for the year of 2010. For this, spatial econometric and instrumental variables models are estimated.

The third essay tests the hypothesis that the risk of losses potentially imposed by fires started in neighboring farms is not accounted by farmers when deciding how to allocate their land among alternative uses. This hypothesis is not refuted by microdata at the farm level, collected through a field survey conducted in the municipalities of Santarém, Belterra and Paragominas. The analysis is restricted to 2009. The technique of Iterated Seemingly-Unrelated Regressions is employed to estimate a system of equations determining how much land is allocated to each class of land of use.

RESUMO

Na Amazônia brasileira, o uso de fogo no suporte à agropecuária se perpetua, apesar de seus efeitos negativos sobre sociedade, meio-ambiente e saúde pública. Dois tópicos do problema são investigados, olhando-se para o período atual (2009-2010) e para três municípios do estado do Pará, nomeadamente Santarém, Belterra e Paragominas. A análise se restringe a motivações e consequências de ordem estritamente econômicas e as queimadas que dão apoio à supressão de floresta primária são mantidas fora do escopo da análise.

O sistema agrícola conhecido por corte-e-queima é utilizado por pequenos produtores como base técnica para o cultivo de culturas anuais. O primeiro ensaio demonstra que a lucratividade do sistema é regida pelo trade-off entre fertilização gratuita via queima da vegetação secundária e ociosidade da terra. Adicionalmente, é estabelecido que, uma redução na duração do pousio, a depender da duração de partida, pode gerar uma sobra de caixa que pode ser empregada no financiamento (ainda que parcial) da transição para uma agricultura livre de fogo.

O segundo tópico estudado é o de incêndios iniciados por atividades agropecuárias, cujas causas e consequências são produto da ação coletiva de diversos produtores, geograficamente próximos.

O segundo ensaio testa a hipótese de que os danos causados ao patrimônio alheio pela perda de controle sobre o fogo não são internalizados pelos produtores quando decidem iniciar uma queimada. Tal hipótese é não refutada por dados georreferenciados referentes ao município de Paragominas e ao ano de 2010. Para isso, são estimados modelos de econometria espacial e de variáveis instrumentais.

O terceiro ensaio testa a hipótese de que o risco de perdas impostas por incêndios iniciados em estabelecimentos vizinhos não é levado em conta pelos produtores, ao decidirem quanto à alocação da terra entre fins alternativos. Tal hipótese é não-refutada por microdados no nível de estabelecimentos agrícolas, coletados por meio de um levantamento de campo, nos munícipios de Santarém, Belterra e Paragominas. A análise se restringe ao ano de 2009. A técnica de Iterated Seemingly Unrelated Regression é empregada para estimar um sistema de equações que determina a área ocupada por cada uma das classes de uso da terra.

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1 INTRODUCTION

1.1 Motivation and thesis structure

In the Brazilian Amazon, fire is employed in the agricultural frontier, to support the establishment, through deforestation, of farms. Also, in areas of consolidated human occupation, extensive cattle ranching and slash-and-burn agriculture (S&BA) employ fire systematically.

From this widespread use of fire as a productive practice, its results soil and forest degradation, microclimate changes (Nepstad et al: 2001), as well as emissions of greenhouse gases. In fact, land use, land use change and forest (LULUCF) accounts for 50-60% of Brazil's emissions of greenhouse gases (MCT: 2010, table 2.9), being the main challenge the country faces to shift to a low carbon economy.

Additionally, there are losses that impact more directly fire users. Being controlled only partially, fire can accidentally spread, causing the destruction of assets owned by multiple agents. There are also, of course, risks to public health and to individual physical integrity.

Results achieved by research programs such as "Studies of Human Impact on floodplains and Forests in the Tropics" (SHIFT), currently called Tipitamba, and "Alternatives to Slash and Burn (ASB)" have demonstrated (for more than a decade, actually) that the dominant use of fire cannot be attributed to the lack of technically feasible alternatives. What is reiterated by the performance of a set of fire-free agricultural systems designed by the Brazilian Agricultural Research Corporation (EMBRAPA)[1].

Fire, however, perpetuates in the Amazonian landscapes. The understanding of the mechanisms governing this perpetuation requires a multidisciplinary effort which is beyond the scope of a PhD thesis. Only two aspects of the problem are investigated, by looking to the current period (2009-2010) and for three municipalities of the State of Pará where human occupation is consolidated, namely Santarém, Belterra and Paragominas. Furthermore, it is considered only the systematic use of fire in fallow agriculture (S&BA) and cattle ranching, keeping out of the analysis the burns that support suppression of primary forest. The analysis is restricted to motivations and consequences with strictly economic nature.

S&BA is practiced by smallholders, especially those located in agrarian settlements established by the federal government, and mainly for growing annual crops. The system's

[1] Among them, (1) the system of slash and mulch (Tipitamba, Denich et al: 2004), (2) the Bragantino System (Cravo et al: 2005) and (3) the system named "*trio da produtividade*" (Alves: 2007).

economic stability depends on the decision regarding the duration of the fallow period. Such is the topic discussed in the first essay. Three questions are addressed:

(i) How does the trade-off between cost-free fertilization and land idleness works?

(ii) Does this trade-off really drive the choice of farms by fallow duration in the Brazilian Amazon?

(iii) Is it possible to manage fallow duration reductions in order to finance the shift to fertilizer-intensive agriculture?

Accidental fires are collective constructs of several collocated farmers, not only in terms of its consequences but also regarding its causes. The social nature of the problem is particularly evident in areas where fire is used recurrently and, hence, a given farmer is exposed to accidental fires eventually caused by other farmers and also exposes the others farmers to accidental fires eventually caused by him/her. Such is the topic discussed in the second and third essays.

The second essay tests the hypothesis that eventual damage to assets belonging to other farmers is not internalized by farmers when they decide to start a fire. For this, spatial econometric and instrumental variables models are estimated with georeferenced data for the municipality of Paragominas and for the year of 2010.

The third essay tests the hypothesis that the risk of losses potentially imposed by fires started in neighboring farms is not accounted by farmers when deciding how to allocate their land among alternative uses. Farm level microdata, collected through a field survey conducted in the municipalities of Santarém, Belterra and Paragominas, is employed. The analysis is restricted to 2009. With the technique of Iterated Seemingly-Unrelated Regressions a system of equations determining how much land is allocated to each class of land of use is estimated.

1.2 Fire use and accidental fires: some evidences from microdata

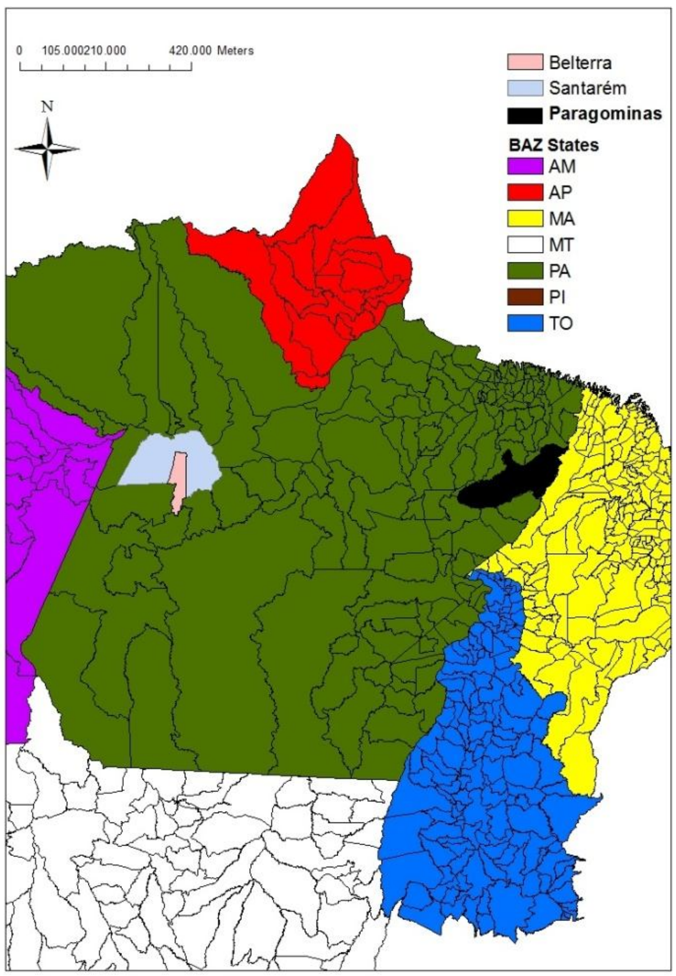
This section presents the main database employed in two of the three essays that follow (the first (second chapter) and the third (fourth chapter)). It also contextualizes agricultural use of fire (AFU) and its practitioners, opening the way for the analysis itself.

1.2.1 The Sustainable Amazon Network

The "Sustainable Amazon Network " (RAS, in its acronym in Portuguese), started in mid-2009 and gathers around thirty institutions, among them, the Universities of Cambridge (UK), Lancaster (UK), Campinas (Unicamp), São Paulo State (USP), Pará State (UFPA), the Pará State Emílio Goeldi Museum (MPEG) and the Brazilian Agricultural Research Corporation (EMBRAPA). It is a multidisciplinary research initiative with the objective of assessing the sustainability of land use / natural resource management systems, located in the Brazilian Amazon (Gardner et al: 2013).

In the first phase, completed in 2011, primary biophysical and socioeconomic data were generated from field collection. A stratified sampling approach was chosen, in which each strata coincides with a microwatershed (34 in total) and representativeness is sought in such level. For this, interviews were conducted in two regions, the first one being composed by the contiguous municipalities of Santarém and Belterra (both in western Pará) and the second one only by the municipality of Paragominas (Southeast of Pará); see figure 1.

Figure 1 Santarém, Belterra and Paragominas in the Brazilian Amazon



A structured socioeconomic questionnaire (whose structure is detailed on the box below) was applied to 488 farms or rented farm parcels located on the municipalites of Santarém, Belterra and Paragominas (state of Pará, Brazilian Amazon). The interviews covered aspects related to welfare, livelihood, demography and agriculture.

Farms were sampled when intercepted by biophysical data collection sites (“transects”) or when randomly selected within each microwatershed (Gardner et al: 2013, data suplement). The microwatershed selection followed the principle of representativeness within classes of the forest cover gradient generated from remote sensing information.

The database that emerged from the survey is referred in this thesis as RASDB and the reader is advised to consult Gardner et al (2013) for further details.

Questionnaire overview

A General data

Module 1 – Interviewed person data and land property status

Module 2 – General data

Property data: land use map, fixed capital (including constructed area), machine (costs, rental, machine-hours) environmental licenses, engagement on associations, rural extension, size of the property (when acquired, now), land rent schemes; Labor employed; Land cleaning and preparation techniques; Fire use and fire management (fire managed area, fire control measures, fire use practices, engagement on collective fire agreements, technical assistance on fire use, source and damage of past accidental fires); Credit and finance.

Module 3 – Forests and hunting

Forests: compliance with the forest/environmental code (conservation áreas), afforestation, timber extraction, invasions; Hunting practices.

B Agricultural data (production and management practices)

Module 4 – Non- perennial crops

Non- Perennial crops: production (soybean, corn, rice, beans, etc - 2006 e 2009: planted area, production, quantity sold, price); practices (inputs per hectare, man-hours, machine-hours, input prices, rotation system), losses (plagues, droughts, rain, theft, fires).

Module 5 – Perennial crops

Same structure of previous module.

Module 6 – Animal production (except cattle)

Production, management practices, losses.

Module 7 – Cattle

Same structure of previous modules

Module 8 – Silviculture

Same structure of previous modules. Highlights: species planted, silvicultural practices (management system), rotation regimes, production finality (self-supply or commercialization), derived production (charcoal, firewood), planted area, production costs (total investments made), engagement on out-grower schemes.

Module 9 – Forest management

Same structure of previous modules. Highlights: species extracted, explored area, forest fire monitoring and prevention, losses imposed by fires.

Module 10 – Land use change expectations

Qualitative data on the plans for land use change
C Demographic and socio-economic data
Module 11 – Household
Household members' wellbeing, demographical structure, access to education, health, entertainment, and migration (past and future), income;

1.2.2 Profile of fire users

In what follows, fire users are defined as farmers that declared to have used fire at least once since they started managing the farm.

As tables 1.1 and 1.2 below show, fire-users can be characterized as smallholders, in most of cases with farms of 100 hectares at maximum. Secondary vegetation covers, in average, more than half of the total area. Non-fire users hold larger properties where pasture and annual crops, soybean, mostly, tends to occupy, comparatively, greater fractions of the farm.

Table 1.1 Total size of farms, distribution of farms by size classes and average size

Classes of total farm area (x)	Non-fire user		Fire user	
	#	%	#	%
x = 1	2	2%	9	3%
1 < x ≤ 100	30	31%	302	84%
100 < x ≤ 10.000	61	64%	47	13%
x > 10.000	3	3%	2	1%
Farms	96	100%	360	100%
Mean	1768		259	

Source: RASDB

Table 1.2 Land use shares

Land use	Non-fire user			Fire user		
	farms	Median	mean (sd)	Farms	median	mean (sd)
Annual crops	52	0.42	0.47 (0.33)	281	0.05	0.13 (0.18)
Perennial crops	16	0.04	0.11 (0.14)	103	0.04	0.12 (0.17)
Pasture	52	0.41	0.45 (0.29)	167	0.3	0.34 (0.27)
Forest plantations	5	0.03	0.1 (0.12)	15	0.03	0.06 (0.05)
Secondary forest	55	0.33	0.36 (0.24)	316	0.57	0.55 (0.29)
Primary forest	44	0.44	0.45 (0.29)	175	0.36	0.4 (0.24)
Other	12	0.06	0.11 (0.15)	35	0.05	0.14 (0.22)

*reduced impact logging and agroforestry were discarded given that only 8 farms declared to develop the first land use and only 4 declared to develop the second.

Source: RASDB

1.2.3 Fire use

Table below, which comes from farmers' recall, show that the share of fire users is relatively stable in the period of 2005-2009. Other point to be noted is that fire is used mostly with the aim of clearing away the forest for growing crops (this is what the table means by "forest").

Table 1.3 Number of farms that have declared to use fire, by land cover burned, 2005-2010*

Land cover burned	2005	2006	2007	2008	2009
Forest	242 (48.5%)	233 (46.7%)	231 (46.3%)	228 (45.7%)	261 (52.3%)
Pasture	44 (8.8%)	38 (7.6%)	41 (8.2%)	41 (8.2%)	47 (9.4%)

* The proportions in parenthesis are given by the ratio of the numbers by 499 (number of farmers). The land cover categories are not mutually exclusive (summing along columns might lead to double counting). The year of 2010 is omitted given that around 50% of the interviews were conducted during 2010. Forest = primary and secondary forest, removed for giving place to the growing of crops. Pasture = burning of pastures overruned by weeds.

Source: RASDB

The federal law which states that the requisition of controlled burning permits is mandatory, whichever the purpose or the size of the area to be treated with fire (IBAMA: 1998), is being followed by less than 4% of fire users in the sample. Even accounting for the fact that the question could be interpreted as if it referred only to 2009, the conclusion remains unchanged.

Table 1.4 Fire users with and without controlled burned permit (issued by the local environmental authority), all fire users and only fire users that declared to use fire on 2009 on after

	Without permit	With permit	Total
All fire users*	355 (96.2%)	14 (3.8%)	369 (100%)
2009 or after	247 (96.5%)	9 (3.5%)	256 (100%)

*Farmers that declared to use fire at least at one of the years of the period 2005-2009.

Source: RASDB

1.2.4 Accidental fires: firefighting and damages

Only 9.8% (47/479) of the farmers reported having lost control over the fire employed into land preparation or into pasture renewal. What seems inconsistent with the fact that 40% (193/479) reported having been victims of accidental fires caused by neighboring farms (external origin). However, the probability of being a victim of an accidental fire is, indeed, theoretically speaking, superior to the probability of starting a fire accident.

By accidental fire is meant an episode of spatial spread of fire not deliberately aimed by the fire starter agent. Then, a farm has in each one of its neighbors an independent source of accidental fires. The probability of being a victim of accidental fires externally initiated, therefore, corresponds to the probability that at least one of the neighbors causes an accidental fire spread. Which is never inferior to the probability that only one agent causes an accidental fire.

Tables 1.5 to 1.8 present some details on accidental fire episodes declared by the interviewees, specifically on firefighting and damages. Regarding the first aspect, it is interesting that the episodes in which fire spread was not fought dominate. What can mean either that the victim became aware of the fire accident too late, or that he/she made the option of not trying to contain the spread.

None of the respondents declared that the fires they started have damaged other farms. Among the 62 episodes of accidental fires reported, related to land preparation or pasture renewal, only 27 (44%) generated losses (only to the fire starter, then). However, of the 217 cases of accidental fires of external origin, 117 (54%) generated losses for the interviewee.

This evidence, together with the comparison of tables 1.7 and 1.8, reveal an asymmetry between episodes of accidental fires caused by the interviewee and accidental fires in which the interviewee was only the victim, not having taken part in their generation. For the first type of accidental fire, it was not declared that other properties were hit and among the damaged assets, productive assets (crops, pasture, forestry and infrastructure) were damaged in 41% of the damage episodes reported. However, for the accidental fires of external origin, most of them hit the establishments of the interviewee, damaging, in 55% of episodes reported, productive assets.

Table 1.5 Classification of accidental fires regarding firefighting, accidental fires started by the interviewee

Who fought the fire?	**#**	**%**
No one (no fight)	17	28%
Farmer only	30	49%
Farmer and neighbors	12	20%
No answer	2	3%
Total	61	100%

Source: RASDB

Table 1.6 Classification of accidental fires regarding firefighting, accidental fires of external origin

Who fought the fire?	#	%
No fight	82	38%
Farmer only	77	35%
Only neighbors	9	4%
Farmer and neighbors	38	18%
Only gov. institutions	3	1%
Gov. institutions and other	2	1%
No answer	6	3%
Total	217	100%

Source: RASDB

Table 1.7 Classification of the accidental fires regarding damages caused, accidental fires started by the interviewee

Asset damaged	#	%
Primary forest	6	15%
Secondary forest	18	44%
Annual crops	1	2%
Perennial crops	0	0%
Forest plantations	0	0%
Pasture	8	20%
Infrastructure*	8	20%
Human health	0	0%
Total	**41**	**100%**

*Fences, constructions and facilities such as flour mills ("*casas de farinha*").

Source: RASDB

Table 1.8 Classification of the accidental fires regarding damages caused, accidental fires of external origin

Asset damaged	#	%
Primary forest	64	23%
Secondary forest	59	21%
Annual crops	7	2%
Perennial crops	13	5%
Forest plantations	2	1%
Pasture	83	29%
Infrastructure	51	18%
Human health	3	1%
Total	**282**	**100%**

Source: RASDB

Forests are the land use more recurrently damaged by fire: of the 41 episodes of damages by accidental fires where the interviewees controlled the source, 24 (59%) hit forests, a figure which is equivalent to 123 (44%), considering the 282 damage cases linked to fire of external origin.

1.2.5 Brief summary

The evidences from RASDB aim to answer two questions:

(i) Who are the fire users of Santarém, Belterra and Paragominas? Owners of holdings not larger than 100 hectares, that keep half of the farm covered with secondary vegetation and use fire, without a permit, with the purpose of preparing the land for growing crops.

(ii) Which are the main impacts of accidental fires? Forest (primary and secondary), pasture and infrastructure and also physical integrity, given that farmers have to fight uncontrolled fires with their own means.

The analysis developed on the three essays that follow lay on such evidences and tries to expand them by connecting theory, information from RASDB and also from additional sources.

2 SLASH AND BURN AGRICULTURE IN THE BRAZILIAN AMAZON: MICROECONOMICS OF FALLOW MANAGEMENT

Abstract

The economic literature generally explains the perpetuation of Slash and Burn Agriculture (SB&A) among Amazonian smallholders on the basis of severe scarcity of production factors except for land. The paper improves this explanation, by bringing into light the role of secondary vegetation both as a cost-free source of nutrients and also as a renewable resource whose efficient management can pave the way to a successful shifting for fire-free agriculture. It is of particular relevance for policy the result that public subsidies to input-and-capital-intensive cropping might be not enough for favoring the shift, owing to path dependence on fallow duration decisions and exposition to unfavorable market conditions.

2.1 Introduction

In the Brazilian Amazon, S&BA keeps being the dominant technical basis of small scale agriculture. This is so because the system is the optimal choice for farmers who face relatively high levels of labor, agricultural inputs, machinery and bank credit scarcity and a relatively low level of land scarcity. This "general hypothesis" sums up the reasons for the perpetuation of slash-and-burn found in some of the studies focused on the economic aspect of the problem (Tomich et al: 1998, Vosti & Witcover: 1996, p.1, Palm et al: 2005, cap.1 e cap.18, Nepstad et al: 2001, p.2[2], Denich et al: 2004[3] e 2005, Carmenta et al: 2011, p.1, Börner et al: 2007, Sorrensen: 2009, Boserup : 1965, cap.6, p.56, Scatena et al: 1996, Mazoyer & Roudart: 2009) [45].

[2] Faced with acid-infertile soil, abundant, inexpensive forestland, and a shortage of labor and capital, the forest itself is the most logical substitute for fertilizer, pesticides and farm machinery. A farmer can prepare na ash-fertilized field, with few pests or weeds, for a mere $50-100/ ha by cutting the forest, letting it dry, and setting it on fire (....) Landholders continue to depend upon fire even after their cattle pastures have been established. Burning is often the cheapest way of killing the tops of shrubs and trees that invade cattle pastures, while favoring forage grasses. In sum, fire is a very eficient land management tool on the Amazon frontier, this efficiency is part of the reason that cattle pastures and slash-and-burn agriculture systems are so widespread in the region (Nepstad et al: 2001, p.2)."

[3] "The burning of fallow biomass has its advantages: it is a cheap and easy practice for land clearing, the ashes reduce soil acidity and supply nutrients to crops, and the heat of the fire eliminates pests and diseases in the field (Denich et al: 2004)."

[4] The reasoning that land abundance, relatively to labor, conducts to an extensive use of the first factor, with long fallows, is generally attributed to Boserup (1965, caps. 1 a 3).

[5] Institutional factors, especially those related to tenure security, also favor SB&A perpetuation (Sorrensen: 2009, p.789, Schuck et al: 2002, Araújo et al: 2010): fire can be a way to ensure control over a piece of land in locations where there is no land market organized and regulated. Sorrensen (2009), defends the thesis that policies of land settlement and entitling and credit concession, conducted in the Brazilian Amazon, create desincentivize farmers to abandon SB&A.

However, this explanation fails to account for a crucial element of SB&A which is the secondary vegetation, a renewable resource, managed by farms through fallow. Its nature of a free nutrient source has been highlighted by some authors such as Angelsen (1994) and Costa (2005). And other environmental functions such as water retention, have also being studied (Klemick: 2011). But a point not yet completely understood is how fallow duration affects the profitability of SB&A.

Most analysis of SB&A performance on Brazilian Amazon focus on crop yield (Denich: 1991, Hölscher: 1997, Denich e at: 2004 and 2005), pointing to a negative relation with fallow duration, when fertilizers are not added[6].

Yield is not, however, the only channel through which fallow duration influence profitability. On a rotational system, the last factor determines, additionally, how land is allocated between crops and fallow, i.e., between productive and idle land. The opportunity cost of land, associated with alternative uses besides fallow, is a permanent source of pressure over S&BA practitioners in the direction of fallow reduction (Kato et al: 1999). The cost-free recovering of soil fertility by fallow vegetation turned into ashes acts as a counterweight, especially when fertilizers are not cheap.

It is from the balance of these two forces, mediated through market prices, that fallow duration determines S&BA profitability. The first goal of the paper is to formalize this principle and to submit the product of such exercise to an empirical test. The two first questions to be answered are: how does the trade-off between cost-free nutrient provision and full land utilization works? Does it really drive the choice of farms by fallow duration in the Brazilian Amazon?

The second goal is to stress a point, as far as my knowledge goes, not mentioned in the literature, namely, the short-term rise of profit level during the transition to a shorter fallow duration. Is it possible to manage such transition in order to finance the shift to fertilizer-intensive agriculture? In what scenarios S&BA intensification can be used as a steppingstone to a successful break with S&BA?

Next section briefly reviews the pertinent literature. Sections 3 and 4 treat separately the two sets of questions and a conclusion follows.

[6] A result that has to be taken with caution after the paper of Mertz et al (2008) which contests the agronomical basis of the argument. Looking to data collected on field in Malaysia and Indonesia they found no statistical significant correlation between fallow duration and S&BA yield. “Management factors” such as labor input, “weeding practices”, “pest management” and “water-related problems” proved to be best predictors of the yield level (Mertz et al: 2008, p.82).

2.2 Microeconomics of SB&A

The microeconomic models that seek to represent the behavior of S&BA practitioners can be classified in two classes: (i) simulation models and; (ii) equilibrium models.

The models proposed by Vosti et al (2002) and Börner et al (2007) belong to the first class. Their peculiarity lies in the incorporation of the dynamics of the nutrient stock into the land allocation decision. And for a limited horizon of 25 years. The objective function is given by the present value of the utility derived from the consumption of goods obtained from the market. Basic itens of food are excluded under the assumption of self-supply from cropping. Börner et al (2007) employs a simpler formulation by focusing on the present value of the profit flow.

The intertemporal nature of the land allocation decision is captured with the consideration of irreversibilities, at least under definite amounts of time. The conversion of primary forest is, for instance, irreversible, whilst the growth of perennial crops is temporary irreversible. What makes land use decisions path dependent.

It is this mechanism and also for stock effects, such as for the level of capital hold by farmers, nutrients and available household labor, that adds dynamic to the model.

Angelsen (1994) proposes a dynamic equilibrium model where the agent, a family of smallholders, maximizes the present value of the profit flow coming from land allocation (the land rent). Only two possibilities of allocation are considered: virgin forest and annual crops, the last one based on S&BA.

Two classical microeconomic models are combined. The first, inspired in the seminal paper by Faustman, which lays the basis for calculating the optimal rotation for harvesting a renewable natural resource, originally a forest (Amacher et al: 2009). A similar problem faced by a farmer which has to choose the duration of fallow.

The second model also comes from a seminal paper, written by Von Thünen. Its foundation lies on the hypothesis that the land available to farmers can be occupied either with forests or with agriculture, except for one point, the village, where production can be sold.

Consequently, Agelsen’s model generates two results: (i) the optimum fallow duration and; (ii) the optimal location of agriculture area, what establishes the frontier between such use and the forest.

The production function assumed by the author incorporates directly the fallow period. It is, therefore, production factor, as labor, the only other factor considered. Although initially mentioning the issue of fallow shortening or, to use the author's term, of rise of "production intensity", the effect of the increase in the share of area annually cropped is not modeled. The duration of fallow only exert influence over the profit through the yield channel, i.e., through nutrient provision. It is, therefore, appropriate to say that in Angelsen's model there is a trade-off between cost-free fertilization and economy of slashing effort.

There is, however, an additional channel through which the fallow period can influence the profit, associated with the labor required for slashing and burning. The fact that the latter tends to increase with the former is incorporated with a component of the cost that increases with fallow duration.

The author considers, for the computation of the average profit per hectare, only the area annually cropped, ignoring the fact that, for the farmer, what really matters is the rent extracted from the whole land area, and only from the "active" part. The cost of opportunity of fraction of land kept idle, under fallow, must be accounted for.

There is another branch of the equilibrium models that cannot be ignored. It is the one that emphasizes the consumption-leisure trade-off (Angelsen: 1994, p.9), which is more relevant the less integrated to markets is the agent, in the case, the "peasant" family (Costa: 1995 and Angelsen: 1994, p.5). The inspiration comes from the pioneering work of Alexander Chayanov, which, as explained by Abramovay (1992) and Costa (1995), assumes that the goal of smallholders is to achieve a predetermined and subjective satisfaction level by channeling the lowest effort level possible to work. The unit of analysis, the family, is irreducible and its material needs are subjective as it is the individual preference relations of standard economic theory. Hence, the main point of these models: it is not possible to grasp, based on the concept of profit maximization, the behavior of production units that mobilize labor mainly via family ties. What is especially common in cultivation from slash-and-burn.

But even relying on a behavioral assumption that differs from the theory of the firm, the maximization of utility from consumption, net of disutility associated with work, yields the same result as the maximization of farm's profit when there is perfect competition in factor and output markets (Börner: 2006, p.40). What comes from the fact that, in both cases, the goal is to generate the highest possible production from the use of a given quantity of production factors, labor, strictly, as generally assumed by the SB&A models under discussion[7].

[7]Alternatively, an autonomous, profit maximizing firm, under certain conditions, employ the same number of factors that a firm controlled by families entitled with profit shares (Mas-Colell et al 1995, p.152).

2.3 The nutrient-land utilization trade-off

2.3.1 Two concepts of intensification

The Ricardian land rent theory states two channels for the increase of agricultural output. First, expansion of the total land area devoted to the activity (extensive margin) and, second, the incorporation of more labor hours to each hectare (intensive margin) [8]. Esther Boserup's (1965) seminal work introduced one extra channel: the increase of time during which every hectare is kept under cropping, what, in a rotational agricultural system comes to be equivalent to the decrease of the area annually allocated to fallow. Or, to the increase of the land use factor, being it measured by the ratio between time under cropping and total rotation time (Angelsen: 1994).

Boserup's innovation focuses the temporal dimension of agriculture, or, more precisely, the frequency into which a plot is cultivated. The increase in this frequency, a synonym of fallow reduction, will be here denominated "boserupian intensification", in opposition to the "classic intensification", the last one meaning the incorporation of more production factors (labor, machinery, inputs) per hectare[9].

2.3.2 Secondary vegetation as a renewable resource

The fallow is a period of idleness, during which land generates no income (Klemick: 2011, p. 103). However, the fact that the secondary vegetation is a source of nutrients of spontaneous growth, i.e., cost-free (Angelsen: 1994, p.1), makes this land use rational[10].

S&BA can be defined as the agricultural system whose main nutrient source is the secondary vegetation. Taking as basis the estimates of S&BA's nutrient budget obtained from field

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[8] Mark Blaug, presenting the Ricardian theory, writes: "As the workforce increases, additional wheat needed to feed the additional stomachs can only be produced, in a given amount, by extending cultivation to less fertile land, and not by applying additional capital and labor-intensive to the land that is already cultivated with diminishing returns (Blaug: 2001, p.112)."

[9] In Blaug (2001, Chapter three, p.99), this type of intensification, to which diminishing returns area associated to, is treated in detail in the section referring to the classical theories of land rent, of Ricardo, Malthus, Torrens and West. However, as Kuntz (1982) reveals, this concept of intensification comes from the Physiocrats. To avoid imputing the concept to only one classical author or school of thought, the generic term "classical intensification" is employed, a term closer to the one used by Boserup (1965 cap.5, pg.43), namely, "the usual definition of intensification".

[10] According to measurements made on field by Sommers et al (2004), the burning of a hectare of secondary vegetation in the Bragantina region of northeast of the state of Para, generates ash and charcoal whose aggregated content of potassium (K) is of 41 to 72 kg / ha, for a fallow of 3.5 to 7 years. The price of the chemical fertilizer, KCl, the potassium source considered by Santos (2008) and one of the sources used in the experiments made by Costa (2012), was, in 2008, in the State of Acre, R$ 1.69 / kg, according to the first author. Considering the share of potassium in one kilogram of KCl (52.44%) the burning of vegetation provides an economy of potassium of R$ 132.12 - R$ 232 / ha (US$66- US$166). For other nutrients, except for Calcium, the economy tends to be considerably lower (the amounts of N and P, for example, contained on the ashes and on the charcoal, range between 3-5kg / ha and 0.7 to 5.7 kg / acre, respectively, according to Sommer et al: 2004, table 4).

measurement (Hölscher et al: 1997, Sommer et al: 2004, Denich et al: 2004), there are two other significant nutrient sources: chemical fertilizers and nutrient deposition from the atmosphere by rainfall.

Be the fixed amount of nutrients in the soil from the secondary vegetation decomposition (ashes, leaves, branches or trunks), considering all the area cultivated annually, represented by S. The nutrient input via fertilizers, considering the same spatial context, is expressed by Q. Likewise, during cultivation, the rain makes a non-negligible contribution, D. However, it is necessary to deduct the amount of nutrients that this phenomenon takes away from the soil via leaching (Hölscher et al: 1997, Blanco & Lal: 2008), L. The balance N = D - L is generally positive, according to measurements made in the state of Pará by authors like Hölscher et al (1997) and Kato (1998a and 1998b). It is this net value that should be considered in the budget.

The sources considered exhaust the possibilities of nutrients transfer to crops, X. Within the area annually cropped, A_c, thus, one must have:

$$X \leq N + S + Q$$

Or, taking the average per hectare:

$$\frac{X}{A_c} \leq \frac{N}{A_c} + \frac{S}{A_c} + \frac{Q}{A_c}$$

What will be written as:

$$x \leq n + s + q \quad (5')$$

2.3.3 Production

The level of annual production is a function of the quantities of nutrients extracted from the soil and the quantity of production factors and inputs incorporated.

There are many nutrients needed for plant growth, but it is reasonable to assume, invoking Liebig's law (Lanzer & Paris: 1981, p.93), that for a given vector composed of the extracted quantities of each nutrient, there is always one and only one nutrient which plays the role of limiting factor. Thus, the vector of nutrients required for plant nutrition can be summarized, without any loss, by the amount of limiting-factor nutrient, X[11].

To factors and inputs, except fertilizers (chemical or organic), one can apply the same reasoning: in a given period there is only one factor that can be said relatively scarcer. This limiting-factor element will have its quantity represented by Z (a scalar, thus). One can,

[11] The term "amount of nutrients" and "amount of the limiting-nutrient" will be employed interchangeably in what follows.

therefore, summarize the effect of the availability of factors and inputs included in the general hypothesis in only one variable.

Based on these simplifications, the following production function can be written[12]:

$$Y = F(X, Z)$$

To make nomenclature more precise, X will henceforth be referred as limiting-nutrient and Z as limiting-input.

It is possible, starting from this production function to obtain the average production level per hectare of land, or yield. In order to do it, it is necessary to assume homogeneity of degree one for the function F () - or that there are no economies or diseconomies of scale, being the returns to scale, constant.

Multiplying the function arguments by $\frac{1}{A_0}$ where A_0 is the extension allocated to SB&A (or fallow agriculture), we have:

$$F\left(X\frac{1}{A_0}, Z\frac{1}{A_0}\right) = Y\frac{1}{A_0} \quad (1)$$

The next step introduces the concept of cropping intensity or degree of intensification in the Boserupian sense.

Let C be the period of the agricultural cycle in which cropping takes place, i.e., where the land is productively occupied, and F the fallow or idle period. The sum of these two periods is what is meant by the agricultural cycle or rotation, T (Mazoyer & Roudart: 2009, p.137-140, Kato et al: 1999). Hence, T = C + F.

Assuming that the land is managed in a rotational scheme in which the area annually cropped is exactly proportional to the duration of the cropping period, C, we have:

$$\frac{C}{T} = \frac{A_c}{A_0} \quad (2)$$

The ratio A_c/A_0 is the rate of utilization of the productive capacity of the land. It is therefore a measure for the Boserupian degree of intensification, usually denoted as land utilization factor

[12] An alternative way of designating the production function f (.) is the following. Let $Y = J(X_1, ..., X_N, Z_1, ..., Z_M)$ be the production function that governs the relation between output level and (a) the set of quantities of each of the nutrients needed for cultivation, $\{X_1, ..., X_N\}$ and; (b) the set of input quantities, except fertilizers, and essential production factors. It is assumed that there is a function f(.) such that $J(k_1(X_1, ..., X_N), k_2(Z_1, ..., Z_M)) = f(X, Z)$, so that therefore, $k_1(X_1, ..., X_N) = X$ and $k_2(Z_1, ..., Z_M) = Z$. The use of Liebig's law of limiting factor (Lanzer & Paris: 1981) can be explained from the choice of a Leontief functional form for $k_1(.)$, i.e., $k_1(X_1, ..., X_N) = \min \{X_1, ..., X_N\}$. Now, for the production factors and inputs, it is necessary to have, as the arguments of the function $k_2(.)$, measures of relative scarcity, for each and all inputs and factors, built from a reference situation. That is, $k_2(.)$: $R^M \rightarrow R^1$, $k_2\ \{Z_1, ..., Z_M\} = \{(Z_i): Z_i = \max \{I_1, ..., I_N\}\}$, where I_i is the value of the relative scarcity measure for the factor/input i (see, e.g, Dixit & Stiglitz (1997), section I).

or Ruthenberg's "R" (Kato et al: 1999 and Angelsen: 1994). This magnitude will be represented by γ.

The average amount of the limiting-nutrient employed by hectare can be written in the following way:

$$\frac{X}{A_0} = \frac{X}{A_c}\frac{A_c}{A_0} = \frac{X}{A_c}\gamma \quad (3)$$

Even being trivial, this sentence is enlightening: given the average amount of limiting-nutrient used annually in the area under cultivation, the average amount of nutrient employed per hectare, from the perspective of the whole SB&A area, increases with the land utilization factor (γ). What is also valid for the factors of production and other inputs, as noted by Boserup (1965, chapter 3) in the particular case of labor: intensification, i.e., the increase of γ, tends to translate into increased number of hours worked per year.

Incorporating (3) to (1), one has:

$$F(x\gamma, z\gamma) = y \quad (4)$$

Where $x = X/A_C$, $z = Z/ A_C$ e $y = Y/ A_0$. It must be bring into attention that, for the calculation of yield, or the output / area ratio, what is relevant is the production obtained on the whole SB&A area and not only in the fraction annually cropped. Being f(x, z) the intensive-form production function, whose image is measured in units of average amount of output per hectare of the whole SB&A area, one finally has:

$$\gamma\, f(x, z) = y \quad (4')$$

The yield on the whole S&BA area is a function of the degree of intensification in the Boserupian sense (γ) and, of the average amounts of limiting-nutrient and limiting-input incorporated to the area annually cropped. The function $\gamma f(x, z)$ is alternatively represented by $g(\gamma\, x, z)$.

2.3.4 Secondary vegetation conversion

The best measure for the return paid by secondary vegetation is the economy of chemical fertilizers, to which the agent has to resort whenever the injection of nutrients through slash and burn is thought to be insufficient for attaining the desirable level of yield.

Let $b = u(t)$, $u(0) = 0$, $u'(.)> 0$ and $u''(.) <0$, the production function that governs secondary vegetation growth, where b is measured in kilograms per hectare. Using the letter ψ to denote the coefficient of conversion of kilograms of vegetation biomass into kilograms of the limiting-nutrient, $b\psi$ gives the amount of limiting-nutrient latent in one kilogram of native vegetation.

Combustion cannot transfer this whole mass of nutrients to the soil. In fact, as the SHIFT research program demonstrated, the volatilization losses are considerable (Hölscher et al: 1997, Kato et al: 1999). Furthermore, the conversion into ashes is never complete, always remaining a considerable proportion of secondary vegetation fragments (twigs, leaves and trunks) semi-or non-carbonized (Righi et al: 2009). These, for their turn, can be used for other purposes, energy production, generally (Denich et al: 2004, p.95), in the form of firewood or charcoal (Lopes: 2006). What leads to the assumption that only part of the biomass not turned into ashes is turned, through decomposition, into nutrients.

Given the qualifications, $b\psi$, the mass of limiting-nutrient accumulated in one hectare of secondary vegetation, unfolds into (a) transfer of nutrients to the soil, "s" and (b) transfer of nutrients to other destinations "o". The latter comprises the mass of nutrient-limiting factor volatized (Hölscher et al: 1997).

The ratio $\lambda = s / b\psi$ [13] gives the rate of fixation of nutrients in the soil or efficiency of slash-and-burn, measured in terms of the mass of a specific nutrient made available to crops[14]. What is thus relevant is not b, this simply the amount of biomass accumulated per hectare, but $s = b\psi\lambda$, the amount of nutrients effectively made available to crops.

Thus being, for fixed values of ψ and λ, $s = u(F)\psi\lambda$ gives us the total amount of limiting-nutrient fixed in the soil with the burning of one hectare of secondary vegetation grown over a fallow period of F years. Since $F = (1 - \gamma) T$, it is possible to write: $s = u((\gamma - 1) T)\psi\lambda = s(\gamma, \Omega)$, where Ω is the vector that contains all the other variables, besides γ, that affect the total amount of nutrients fixed in the soil by the burning of secondary vegetation. The following conditions apply: $s(0, \Omega) = 0$ and $\partial s(\gamma,\Omega) / \partial\gamma < 0$.

2.3.5 Framing the trade-off

Be w the price of chemical fertilizer measured in kilograms of the limiting-nutrient, i. e, \$ / kg of nutrient. And denominating by c the price of the limiting-factor, the total annual expenditure made for slashing, burning, fertilizing and cropping the land is:

$$C(Q, Z) = wQ + cZ \quad (6)$$

Taking the average value by hectare, one has:

[13] Righi et al (2009) uses a more rigorous definition, in terms of carbon content, considering, however, not nutrient fixation by fire, but the removal of secondary vegetation.

[14] The burning efficiency in the sense of the text (nutrient fixation) is given by $s_a / (s + o)$, being s_a the amount of nutrients contained in the ash. A broader definition is used, $s / (s + o)$, which incorporates the possibility of decomposition of the biomass that is not reduced to ashes, a source of nutrients that tends to be important in practice. That's why the term "efficiency of slash-and-burn" is employed instead of burning efficiency.

$$C(Q, Z) = w\frac{Q}{A_0} + c\frac{Z}{A_0} = wq\gamma + cz\gamma \ (6')$$

The average income per hectare of the whole S&BA area, for its turn, is given by the product of the ouput price, p, for the total amount produced by hectare, y. Thus, pg(γ, x ,z) = pγf(x,z). The average profit generated by SB&A is given by[15]:

$$\pi(\gamma, x, z, q) = \gamma[pf(x,z) - wq - cz] \ (7)$$

The farm's goal can, therefore, by enunciated as:

$$\text{Max}_{(\gamma,\ x,\ z,\ q,\ \eta)}\ \gamma[pf(x,z) - cz - wq] \text{ s.a.}\begin{cases} x \leq n + s + q \ (a) \\ s = s(\gamma, \Omega) \ (c) \end{cases}$$

To make things simple, it will be assumed that n = 0 and p will be taken as the reference for the measurement of monetary variablels (*numerárie*), i.e., p =1. The problem reduces to:

$$\text{Max}_{(\gamma, q,\ z)}\ \gamma\{f(s(\gamma, \Omega) + q, z) - cz - wq\}$$

First order conditions are[16]:

(FOC1) $\frac{\partial}{\partial\gamma}[\pi(\gamma, q, z)] = 0 \rightarrow \hat{\pi} + \gamma\frac{\partial f}{\partial x}\frac{\partial s}{\partial\gamma} = 0$

(FOC2) $\frac{\partial f}{\partial x} = w$

(FOC3) $\frac{\partial f}{\partial z} = c$

While π denotes the ratio of total profit, R, by the whole S&BA area, $\hat{\pi}$ indicates the ratio of total profit by the area annually cropped – fallow area is, therefore not considered in the denominator of the last variable. Thus, $\hat{\pi} = \frac{\pi}{\gamma}$.

The last two first order conditions express the fact that it is optimal to contract a quantity of a given factor which is just enough to make marginal productivity equals the amount paid for each unit. What is in accordance with microeconomic theory (Varian: 1992, chapter 2, and Mas Collel et al: 1995, chap. 5).

The other first order condition bring into light the two channels through which changes in the degree of intensification, γ, impact the profit generated by S&BA. The formula on the figure below is clarifying. It shows the effect of an infinitesimal variation of γ over the total profit, R, by taking into account two facts. First, $R = A_0\pi$ and, second, $\partial s / \partial \gamma < 0$.

Figure 2 Partial derivative of the total profit in respect to the land utilization factor

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15 The role of "profit multiplier", played by γ, is a peculiarity of homogeneous functions, as pointed out by Varian (1992, p.29).

16 Appendix A.2.1 presents the second order conditions.

$$\frac{\partial R}{\partial \gamma} = A_0 \Bigg(\underbrace{\hat{\pi}}_{\substack{\textbf{Land utilization} \\ \textbf{channel}}} - \underbrace{\gamma p \frac{\partial f}{\partial x} \left| \frac{\partial s}{\partial \gamma} \right|}_{\textbf{Yield channel}} \Bigg)$$

The first term inside the parenthesis measures the variation of the average profit per hectare, caused by the variation of the share of the area devoted, annually, to cropping, under the hypothesis that the average profit, per hectare, calculated from the whole SB&A area, does not change - $\hat{\pi}$ is kept constant, while γ varies. The second term represents the opposite possibility: the fraction of the land annually cropped is taken as fixed (γ) and $\hat{\pi}$ is altered.

The last term inside the parenthesis represents a chain of effects. In the first place, when the degree of intensification (γ) is incremented, there is a reflex in the amount of nutrient fixed by the burning of secondary vegetation ($\partial s/\partial \gamma$). This first effect turns into the variation of the yield ($\partial f/\partial x$). In a third stage, the impact extends to the average income, which changes in a magnitude equivalent to $\frac{\partial f}{\partial x}\frac{\partial s}{\partial \gamma}$ .Given that such income consists in the ratio of the total income by the area annualy cropped, A_c, it is necessary, to have the effect in the average profit, calculated for the whole SB&A area, A_0, to multiply $p\frac{\partial f}{\partial x}\frac{\partial s}{\partial \gamma}$ for γ.

2.3.6 Secondary vegetation rent

The equilibrium condition, given by FOC1, can be reformulated in two ways that make interpretation more straightforward. For this it is necessary to resort to the properties of homogeneous functions of degree one, as detailed in Appendix A.2.2.

$$\hat{\pi} = ws(\gamma, \Omega) \quad (8.1)$$

$$\varepsilon_{\gamma}^{s}(\gamma, \Omega) = -1 \quad (8.2)$$

The first condition says that in equilibrium, the average profit per hectare (π) equals the value of the nutrients coming from the average mass of secondary vegetation accumulated per hectare. This value is equivalent to the expenditure on fertilizers that would have to be made by the agent whether he/she had chosen to achieve the same agricultural productivity with fire-free methods, i.e., through fertilization. It is, thus, the economy of fertilizers provided by S&BA.

More can be said about the sentence 8.1. It reveals a crucial point: S&BA pays an economic rent associated with the peculiarity that, in such system, one of the production factors is not remunerated, the nutrients from fallow vegetation. What is more rigorously established in the following version (see item v.d of Appendix A.2.2):

$$R = wS > 0 (8.1')$$

R is the total profit and S the total amount of nutrients, not to be confused with the average amount of nutrients fixed per hectare, this last one represented by $s(\gamma, \Omega)$.

Fertilizer-based agriculture, where fallow is not developed[17], is characterized by $\gamma = 1$. What is equivalent to state that the whole available land (A_0) is occupied only and solely with crops, along all agricultural cycle. Without secondary vegetation, $s(1,\Omega) = \psi\lambda b((1- 1)F) = 0$. What reveals a fundamental point: in fallow-free agricultural systems all production factors are remunerated. The rent paid to the farmer, in equilibrium, and with a constant-return technology, is, thus, zero. This fact is established below:

$$\hat{\pi} = ws(\gamma, \Omega) \rightarrow \frac{\pi}{\gamma} = ws(\gamma, \Omega) \rightarrow \pi = ws(1, \Omega) = 0 \ (8.1'')$$

What is the same as stating that:

$$R = 0 \ (8.1''')$$

The comparison of conditions 8.1' and 8.1''' leads to a non-negligible progress in the understanding of the mechanism of SB&A perpetuation. Whilst the general hypothesis (introduction) focuses in factor scarcity for explaining the phenomenon, the model proposed highlights the relevance of the abundance of secondary vegetation, what does not reduces to the idea of land abundance contemplated in such explanation[18].

The second condition, 8.2, refers to the elasticity of the mass of cost-free nutrients accumulated on average per hectare. Its interpretation is only possible when two facts are considered. First, (as shown in Appendix A.2.2, item vii) the magnitude of the elasticity responds negatively to γ. Second, given that the average amount of cost-free nutrients accumulated per hectare falls with the land use factor (i.e., $\frac{\partial s}{\partial \gamma} < 0$), the sign of the elasticity is always negative.

That said, it follows that, by condition 8.2, the balance is achieved for a value of γ at which a further increase of the annual cultivated area would revert to more than proportional fall of the

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[17] In practice, there are alternative systems in which the land is subjected to a period of rest, but only after considerably long periods of uninterrupted cultivation. Not being common on these systems to take advantage of the ashes of vegetation, as a source of nutrients, their omission from analysis does not limit/distort the conclusions.

[18] That's because the abundance of land, even being a necessary condition, is not sufficient for abundance of secondary vegetation. The first condition can be met in a region where soil fertility cannot be satisfactorily replenished from the burning of secondary vegetation, owing to “over-shortening” of fallow.

average amount of cost-free nutrient fixed by hectare. The farmer, therefore, has an incentive to increase the degree of intensification while, by doing it, he/she induces a less than proportional reduction of the mass of nutrients provided by secondary vegetation. From that point on, the incentive to further increase the land use factor ceases to exist[19].

2.3.7 Testing the empirical validity of the trade-off

The optimal level of the land use factor that comes as a result from the solution of the trade-off problem discussed in the last sessions can be represented as $\gamma^* = \Lambda(c, w, \Omega)$. The precise functional form of $\Lambda(.)$ depends on the assumptions made about the functional forms of the production function,$g(\gamma, x, z)$ and of the function of growth function for fallow vegetation, $b(F)$. Fortunately, no assumption is needed if the goal is only to know in what direction the the parameters influence the equilibrium level of γ, i.e, if they exert a positive, negative or null impact. For this, the comparative static analysis, detailed in appendix A.2.3, is fully sufficient. Ir results in the following signals for the parameters' influence:

$$\begin{bmatrix} S\left(\frac{\partial \gamma^*}{\partial w}\right) & S\left(\frac{\partial \gamma^*}{\partial c}\right) \\ S\left(\frac{\partial q^*}{\partial w}\right) & S\left(\frac{\partial q^*}{\partial c}\right) \\ S\left(\frac{\partial z^*}{\partial w}\right) & S\left(\frac{\partial z^*}{\partial c}\right) \end{bmatrix} = \begin{bmatrix} -1 & -1 \\ -1 & -1 \\ -1 & -1 \end{bmatrix}$$

The biophysical parameters vector, Ω, is suppressed, given it contains a set of variables whose aggregate influence over γ^* is a priori unknown. Only the first row is of interest for a model where the optimal value of γ is the dependent variable.

One way to test the empirical validity of the trade-off is to submit the signals of influence indicated by comparative statics (first row of matrix) to refutation with a dataset. The following linear model can be estimated:

$$\gamma^* = \beta_0 + \beta_1 c + \beta_2 w + \beta_3 \Omega + u$$

Next subsection presents the main conventions employed to gather the appropriate data from RASDB.

2.3.8 RASDB

2.3.8.1 Land use factor

The land use factor, γ, was not the object of any question of the survey, but it is possible to estimate it if the duration of cropping, C, is assumed to be equal to one year (as done Metzger:

[19] It is worth noting the similarity with the solution of the problem of the optimal level of production faced by a monopolistic firm (Nicholson: 2002, p.499).

2002, p.423, for the case of the Bragantina region of Pará state). Under such hypothesis, T becomes equal to 1 + F and then, the following equation applies: $\gamma = 1/(1+F)$.

The assumption of C =1 is justified in basis of estimations for C that take as basis the fact that, if a perfect rotational fallow-cropping system truly prevails in practice, such magnitude should be equal the ratio of the area annualy cropped by the area annually treated with fire. What, for its turn, comes from the following reasoning: if the land is cropped during C years (under perfect rotation) the extension of the area annually cropped is equal to the area slashed and burned in the same year plus the area slashed and burned on the last C - 1 years.Table bellow presents the results of the calculus, from RASDB data, of the ratios referred.

A tolerance of 0.05 years (0.6 months) was used to round the ratios, thus obtaining integer values for C. For the two years for which the required information was available, almost 75% of the farmers registered an estimated land use factor equal to the unity.

Table 2.1 Statistics for estimated cropping period duration (C)

Year	count	min	Max	mean	sd	p10	p25	p50	p75	p90
2006*	157	0.02	3.08	1.10	0.43	1.00	1.00	1.00	1.00	2.00
2009	157	0.06	8.00	1.11	0.70	0.84	1.00	1.00	1.00	1.50

*for 2006, data comes from recall questions on land use and burned areas.

There are 18 farmers in the sample that do not practice S&BA, obtaining nutrients for growing annual crops solely from fertilizers. For these cases, the land use factor is defined to be equal to to the unity (no fallow).

2.3.8.2 Proxying market accessibility

Owing to the cost of conducting data collection, the database available covers two small regions of Brazilian Amazon, both located in the same state, Pará. Within each region, the sampled farms are proximate and thus tend to differ not significantly in terms of the market prices faced. That is because, the closer two farms are, the larger the probability of exchanging inputs and outputs in common local markets (this issue is better discussed in section 4.2.1.1 of chapter 4).

A consistent way out is to use not the market prices but the prices actually received or paid by the farmer. These ones can be written as $p = p^{OM} - d^{OM}$, for the ouput and $w = w^{IM} + d^{IM}$, for the case of inputs, such as fertilizers, where p^{OM} and w^{IM} are, respectively, the price for which the output market buys farmer's output and the price for which the input market sells inputs to the farmer. The symbols d^{OM} and d^{IM} represent the distances to the closest locations where each kind of markets can be found. Consequently, the "real" price of fertilizers, w/p, which is the parameter of the model - reminding that p is assumed to be equal to the unity (numérarie) - takes the following form:

$$\frac{w}{p} = \frac{\mathrm{w}^{IM} + d^{IM}}{\mathrm{p}^{OM} - d^{OM}}$$

This way, all the variation of the explanatory variable in the cross-section of farmers - in the most plausible case where the farmers sampled operate in common markets, as already discussed -, concentrates in the transport cost.

A measure for transport cost, coherent with the economic theory, is the opportunity cost of the time invested in travelling to the nearest market (Duflo et al: 2008). To proxy this opportunity cost, the travel time, declared by respondents, is employed, given the unavailability of a measure for the opportunity cost per unit of time (minute, hour). The imprecision of such proxy is (partially) mitigated by focusing in a subsample of smallholders engaged mostly on annual cropping, what reduces the intra-sample heterogeneity of the opportunity cost of time.

The nearest market for outputs and inputs, for its turn, can be proxied by the location of the nearest urban centers. The main drawback of this approximation is to make undistinguishable the individual effect of the two prices considered, namely, the price of output, p and the price of fertilizers. With this simplification, the real price of fertilizers turns to:

$$\frac{w}{p} = \frac{\mathrm{w}^{IM} + d^{UC}}{\mathrm{p}^{OM} - d^{UC}}$$

What is an increasing function of the transport cost to the nearest urban center, d^{UC}.

2.3.8.3 Labor scarcity

Most of the farmers can find labourers to hire in the municipalities where they are located, as table below indicates. Therefore, the transports costs incurred for hiring labor tend to be negligible.

Table 2.2 Municipalities from where the hired labor comes

The labor you hire comes from...	
Your municipality/neighbor municipalities*	45
Other municipalities	10
No aswer	117
Total	**172**

*the only neighborhood considered is Mojui dos Campos, Santarém and Belterra, three municipalities that share borders.

Source: RASDB

Nevertheless, only farmers that hired labor on the time they were interviewed declared wages generally paid but only the minority of them, as table below shows.

Table 2.3 **Count of interviewees (farmers) by status of the answers to the questions requiring the wages paid, by type of worker (permanent or temporary)***

Type of worker / farmer's answer	Have declared the wage	Have not declared the wage	Total
Wages paid to permanent workers	8	77	**85**
Wages paid to temporary workers	51	34	**85**

*only farmers that hire labor are considered (85 farmers in the subsample of 172 farmers grows traditional annual crops (see section 2.3.8.4) for the criteria that defines the sample).

Source: RASDB

An alternative measure of labor scarcity is given by a question on perceived (subjective) labor scarcity. It is a question of of multiple choice, allowing only four responses, which are: "I always can find (labor)", "easy to find", "hard to find" and "does not exist here." The dichotomous variable (dummy) incorporated into the model takes unitary value in the case where the respondent expressed accordance with at least one of the first two replies and disagreement with the other two. In the situation diametrically opposed (disagreement with the first two and agreement with at least one of the last two), the dummy takes the value of zero. Any other possibility is disregarded: the 144 observations where this was detected were eliminated from the sample.

2.3.8.4 Biophysical features (Ω) and further variables

When no measures for recovering fertility and control erosion are employed, soil quality of farms where S&BA prevails tends to decrease with time, especially under fallows of four years or less[20] (Sommer et al: 2004, Kato et al: 1999, Blanco & Lal: 2008, p.10). As table below reveals, this seems to be the case for most of the sampled farms.

Table 2.4 **Count of interviewees (farmers) by answers to the questions regarding the employment of soil quality practices**

Practice / answer	Yes	No	No answer	Total
Employ fertilizers?	33	139	0	172
Apply lime?	8	163	1	172
Monitors fertility?	4	168	0	172
Conducts fallow for more than 4 years?	44	104	24	172

[20] What is called “short fallow” in Metzger (2002).

Source: RASDB

Thus being, the timespan the farmer is managing the farm can be employed as a proxy for the quality of soil. Of course, differences on the quality of the soil of farms that are not explained by the management choices of the farmers that controlled them when the survey was conducted (2010-2011), cannot be captured by such measure and will be left for the error term since no direct measure of soil quality is available.

One way to partially mitigate this imprecision is by controlling to other biophysical caracteristics potentially correlated with soil quality, as it is the case of the slope of the terrain, a topographic feature that can be related with erodibility of farm's soil (Blanco & Lal: 2008, table 1.3, p.9). The average slope is calculated for buffers of 100 meters from farms headquarters – the location of headquarters is the only information available in RASDB for capturing the location of farms.

Other limitation of the timespan proxy lays on the fact that it tends to capture other factors such as farmer's experience in managing the farm, as Perz & Walker (2002, p.1014) and Coomes et al (2000, p.115) make it clear. What cannot be addressed, so the covariate in question has to be seen as generic measure that can capture multiple effects, being soil quality only one of them.

Educational level is included as a measure for human capital and also a regional dummy that controls for peculiarities of the two regions covered by RASDB.

The educational level dummy indicates with unitary value that the person that answered the questions regarding land use and production has educational level above the "lower secondary level of education", as defined by the International Standard Classification of Education (ISCDE 1997, OECD: 2011, p.9). The goal is to control for the level of human capital hold by the agents that make land use decisions (Vosti & Witcover: 1996, Alix-Garcia et al: 2005, p.229, Parman: 2012, p.17), what is related to the ability to obtain and analyze the relevant information (Parman: 2012, p.17, Schultz: 1975).

2.3.8.4 Model estimated and sample

The econometric model to be estimated, after adjusting for the limitations of the available data is:

$$\gamma^* = \beta_0 + \beta_1 urb\_t + \beta_2 exp + \beta_3 educ + \beta_4 labor + \beta_5 slope + \beta_6 region + \beta_7 exp*region + u$$

The notation of the variables and also their measurement units are described on table 2.5. The interaction between the duration of management and the regional dummy is included owing to the significant correlation between the two covariates.

Table 2.5 Variables of the model

#	Variable	Notation	Measure for?	Unit
0	Travel time to the nearest urban center	urb_t	Market access	Minutes
1	Duration of managment	exp	Soil quality, farmer's experience	Years
2	Educational level dummy (= 1 if the farmer has educational level above the lower secondary, 0 otherwise)	educ	Knowledge	Binary
3	Hired labor availability dummy (= 1 if interviewee has reported easiness of finding labor to employ, 0 otherwise)	labor	Labor scarcity	Binary
4	Slope within 100m of farm headquarters	slope	Biophysical features of the farm	Percentage (100%)
5	Region dummy	region	Regions' peculiarities	Binary
6	Interaction between the regional dummy and duration of residence	reg * exp	Knowledge	Years

Only farmers with positive areas allocated to annual crops in 2009, excluding soybean producers, are part of the estimation sample. The exclusion is justified owing to the goal of focusing only on crops traditionally grown with slash and burn, what is not the case of soybean, a crop recently (on the 90's) introduced in the Brazilian Amazon, that were since form the start, cultivated with tractor-and-fertilizer-intensive methods.

Further exclusions were needed, owing to data availability. Farmers that have not declared whether they practiced fallow or not were excluded, as well as farmers that have not declared whether they use fertilizers (chemical or organic) or not. Farmers that declared to use neither fertilizers nor conduct fallow but had positive annual crop areas were excluded, since there are no other sources of nutrients for crops. These cases, therefore, can only be are due to survey errors or to misinterpretation of the questions.

Finally, two outliers for the total farm land are not accounted for (their areas are more than 170 times larger than the 90° percentile of 100 hectares).

The statistical summary of model variables can be found on tables 2.6, where the labor dummy is excluded and on table 2.7 where the labor dummy is included. Theses two cases are considered since the inclusion of the labor dummy reduces the sample considerably, owing to missing data.

Table 2.6 Summary of variables without labor dummy

Variable	N	Mean	Standard deviation	Minimun	Maximum
γ	162	0.33	0.28	0.09	1
urb_t	162	110.17	61.51	2.00	300.00
exp	162	19.86	13.79	1	60.00
educ	162	0.07	0.26	0	1
slope	162	3.69	2.43	0	14.33
region	162	0.31	0.46	0	1
reg*exp	162	3.70	7.96	0	42.00

Source: RASDB

Table 2.7 Summary of variables with the labor dummy

Variable	N	Mean	Standard deviation	Minimun	Maximum
γ	116	0.36	0.30	0.09	1
urb_t	116	109.61	62.17	5.00	300.00
exp	116	18.23	13.94	1	60.00
educ	116	0.06	0.24	0	1
labor	116	0.73	0.44	0	1
slope	116	3.44	2.22	0	13.28
region	116	0.43	0.50	0	1
reg*exp	116	5.16	9.01	0	42.00

Source: RASDB

2.3.9 Estimation results and discussion

Table 2.8 Estimation results without the labor dummy

y = land use factor (γ)	**OLS**	**FLOGIT**	**FPROBIT**
urb_t	-0.00126**	-0.00636**	-0.00355**
	(0.00043)	(0.00217)	(0.00124)
exp	-0.00345*	-0.01643*	-0.00983*
	(0.00141)	(0.00659)	(0.00396)
educ	0.21847*	0.93136*	0.58496*
	(0.10533)	(0.43498)	(0.27985)
slope	-0.00992	-0.06774	-0.03636
	(0.00728)	(0.03738)	(0.02137)
region	-0.03011	-0.08582	-0.06827
	(0.07114)	(0.31939)	(0.19567)
reg*exp	0.00713	0.03011	0.01869
	(0.00447)	(0.01834)	(0.01191)
cons	0.54085***	0.35771	0.16947
	(0.06862)	(0.31842)	(0.18828)
N	162	162	162
r2_a	0.20022	DA	DA
F	5.26919	DA	DA
chi2	DA	28.43143	29.09718

Standard errors in parentheses * p<0.05, ** p<0.01, *** p<0.001

Table 2.9 Estimation results with the labor dummy

y = land use factor (γ)

	OLS	**FLOGIT**	**FPROBIT**
urb_t	-0.00165**	-0.00801**	-0.00454**
	(0.00056)	(0.00279)	(0.00158)
exp	-0.00342	-0.01554	-0.00925
	(0.00202)	(0.0091)	(0.00552)
educ	0.1688	0.68198	0.43512
	(0.15349)	(0.66555)	(0.41915)
labor	-0.09697	-0.45968	-0.28114
	(0.0694)	(0.30279)	(0.18587)
slope	-0.00645	-0.04134	-0.02432
	(0.00915)	(0.04531)	(0.02599)
region	-0.02577	-0.07052	-0.05298
	(0.08111)	(0.35931)	(0.2207)
reg*exp	0.00697	0.03	0.01812
	(0.0046)	(0.01923)	(0.01241)
cons	0.65628***	0.82646	0.47108
	(0.10528)	(0.45846)	(0.27992)
N	116	116	116
r2_a	0.18231	DA	DA
F	3.41315	DA	DA
chi2	DA	21.63573	22.44423

Both ordinary least squares (OLS) and fractional logit (FLOGIT) estimations do not refute the hypothesis market access is positively correlated with the value of the land use factor, being the labor dummy included or not (what makes a relevant difference in terms of the size of the sample). This is in accordance with the comparative statistics analysis, since more market access means a lower real price for fertilizers, and this last variable exerts a negative impact on the land use factor. The cost-free-fertilization-land-idleness-trade-off is, therefore, not refuted.

The labor dummy is not significant, what is not in line with the comparative statics, which foreseen a negative effect of the (real) wages over the optimal land use factor.

The duration of time the farmer is managing the farm is significant only for the larger sample.

2.4 Profit overshoot

2.4.1 Motivation

Evidences from a fieldwork conducted on March 2012 in an agrarian settlement, eastern Amazonia[21], inspire the study of alternative paths for shifting to fire-free capital-and-input-intensive agriculture. Fifteen smallholders were interviewed on a semi-structured basis, twelve of them having already gone through experiences of making the shift (appendix A.2.4). Their case is of special interest given the contemplation, of the settlement, with local government subsidies targeted at supporting a modality of annual cropping that starts with mechanized clearing of the secondary vegetation and depends on the addition of chemical fertilizer to the soil. Tractors, operators and fuel are made available with no cost for farmers as well as seeds of maize and other inputs (more details on appendix A.2.4). Even under such favorable conditions, three main barriers to shift could be observed on field.

1. Lack of knowledge regarding fertilization techniques. Without proper assistance by rural extensionists, crop yields can be driven below the level attained with slash-and-burn of secondary vegetation[22];
2. Lack of money to cover the whole cost of an input-intensive agricultural system, what induces partial adoption of the proper technical itinerary;
3. Lack of access to output markets or remoteness, what sets an upper limit to profitability, deincentivizing yield increases.

Focusing on the second barrier (and, thus, abstracting the remaining ones), a question promptly arises: what are the feasible paths for credit-restricted farmers to build a solid way out of SB&A? To answer it, a more abstract, theoretical, analysis will be sought on what follows.

One possible answer lays on the temporary rise of the total profit obtained from the whole fallow agriculture area during transitions to shorter fallow regimes. When, in a given year, a farmer decides to reduce the minimum age from which secondary vegetation is cut, he/she will find parcels above the new (lower) threshold (“over-matured” trees, Conrad: 1999, p.69), whenever he has been practicing rotational cropping. This surplus biomass is a natural capital - in the sense of Daly & Farley: 2003, p.17 - of short existence, whose sacrificing can raise total profit to a level that is above the one attained up to the present time and also above

[21] The real location is omitted to preserve interviewees’ anonymity. Appendix A.2.4 details the fieldwork.

[22] Learning gradually through trial-and-error can be frustrating given that surprisingly unsuccessful outcomes can emerge (Conley & Udry: 2010).

the level that will be attained on the new fallow regime, when no vegetation with age above fallow duration will exist.

The “profit overshoot” happens because the transition to a shorter fallow breaks the nutrient-land utilization trade-off studied on section 3. Comparing the situations before and after the transition, it looks like nutrient availability was traded-off for broader land utilization. But, looking for the intermediary situation, the transition stage, the sacrificing of surplus biomass (i) overshoots the yield above the level that will prevail on the next stage, on the parcels with secondary vegetation above the new cutting age and; (ii) make the land utilization factor go beyond the level practiced since then. For a short period, the farmer can live as if the trade-off does not exist, profiting from the simultaneous sudden rise of cropping area and from the rise of yield above the level compatible with the new fallow regime.

To be more precise, the term “profit overshoot” should be replaced by “biomass overshoot” or “production overshoot” since what is overshoot is (i) the amount of biomass accumulated on the parcels above the new minimum cut age, compared to its future (next-cropping period) level and; (ii) the crop area, compared to its past level. To stress the physical nature of overshoot is necessary, because, even being that biomass overshoot will always occurs during transition, concomitant rises in input prices and/or falls in output prices can have a sterilizing effect, preventing the farmer to obtain a higher amount of profit. Such phenomenon is designated by the term “increase in the short-run timber supply” by Amacher et al (2009, p.29) and Conrad (1999, p.69), when the authors examine the effect of input and output price variations over the (optimal) rotation – the equivalent to fallow duration - practiced by forest plantations firms.

There is, nevertheless, one scenario where production overshoot will not occur, owing to the impossibility of a yield overshoot. It refers to the case where fallow vegetation above the new harvest age does not have a greater fertilizing power, after being slashed and burned, than fallow vegetation whose age just meets the new threshold. Then, yield on parcels fertilized with ashes of vegetation above such level will be just equivalent to the level that can be generated on the remaining parcels and no overshoot will occur: the amount of production obtained during transition to the new regime will be the same that will prevail after transition is completed.

Taking the reasoning beyond, it is correct to state that, at least at one of the years of the lifetime of a farm located in the Brazilian Amazon (or in other region of the globe where forest grows spontaneously), a production overshoot occurs. At least on the year where primary vegetation was slashed and burned, and the land start being managed, production overshot its future level.

This "all-at-once" assumption retakes the "Barbecho[23] crisis theory" (Maxwell: 1986, p.165, Thiele: 1992, Reynal et al: 1996, p.34), elaborated from the observation that Bolivian Amazon smallholders watched the yield of their SB&A areas decline dramatically when, after having converted all primary vegetation into ashes, were inevitably led to the cultivation of areas covered with secondary growth. It cannot, however, be applied to the case of Brazilian Amazon, a region where, as demonstrated by agronomic research (Kato et al: 1999, table 2, Denich et al: 2004 and 2005, figure 5, Sommer et al: 2004, p. 269, Reynal et al: 1996, p.36), non-negligible differences in fallow lead to non-negligible differences in nutrient accumulation and, consequently, to non-negligible differences in yields[24], depending, of course, on the crop[25].

If the fallow reductions are generally insignificant, not larger than one year, for instance, the yield overshoot tends to be irrelevant. Evidences from research, although, suggest that it is most probable that, at least the first fallow reductions that an Amazonian smallholder conducts in a given land area, have an order of magnitude not bellow three years[26]. The general trajectory followed by S&BA practicing smallholders stars from primary forest or from fallows of ten years or more[27] and turn into a progressive fallow shortening, reaching levels low enough for a further shortening to revert into a negligible rise of yield (Metzger: 2002, p.427-428). If, on this path, they end in a situation where the overshoot is not possible, this is because they have profited from overshoots in the past.

[23] "Barbecho" stands for secondary vegetation in Bolivia.

[24] Uncorrected by the land use factor (in the sense of Kato et al: 1999, table 7) i.e., considering only the crop masses obtained from a cropped hectare and not the average across the whole fallow agriculture area (as one has on table 3 of the mentioned paper).

[25] Cassava, for instance, did not presented a statistically significantly different yield under 4-year fallow compared to 10-year fallow, on the experiments conducted by Kato et al (1999, table 7).

[26] In the sample of 68 small landholdings surveyed by Scatena et al (1996, p.35), on 1992, in the municipality of Santarém, State of Pará, the most recurrent trajectory persecuted by a farmer starts with the slash and burn of primary forest or 8-12 years old secondary vegetation. Then, on the second phase, a fallow of 1-2 years starts being practiced. What means a fallow reduction of at least 6 years. In the third phase, fallow is increased to 3-6 years, in order to recover the yield. And, on the fourth and last phase, farmers decide, from the "site productivity" observed at the end of the third phase, the 8-12 year fallow will be reestablished or not - the average length of ownership of farms on the sample is of 14.8 years with a standard deviation of 2.6 years. Carpentier et al (2000, p.75, figure 1), with a sample of 160 households located on the States of Rondônia and Acre, find out that the predominant paths followed by smallholders also start with primary forest, give place to 2 years of cultivation, and, after this, a fallow of 3 years, or, alternatively cattle raising or, still, perennials growing. Kato et al (1999, p.226), argue that, on the Bragantina region, the fallow duration was, in the late 1990s, around 4 years "instead of the 10 years with the previous generation of farmers, a reduction of 50% in the crop/fallow cycle (from 2/10 to 2/4 years)."

[27] What Metzger (2002) calls the second phase of landscape occupation by SB&A, the first one consisting in the suppression of primary forest.

Conclusively, from a dynamic perspective, it is not correct to claim that there are lands of Brazilian Amazon, suitable for agriculture, where the phenomenon of production overshoot cannot occur. It will always occur somewhere on the productive lifetime of the land. What is correct is to say that its occurrence, in a given period, depends on the previous manifestations of the phenomenon. The higher the yield level attained in a given overshoot, the lower will be the yield level attained in future overshoots, what can eventually lead to the impossibility of new yield overshoots.

The discussion can be summed up under the concept of path-dependent[28] production overshoots. The main foundation lies on the natural capital whose existence is established by the fact that, except for the cases where all vegetation was permanently suppressed from land suitable for agriculture and/or S&BA is not practiced, there is always vegetation above a shorter fallow duration that might eventually be defined in the future.

The next subsection use simulations[29] to illustrate how path dependency of production overshoots can be managed to pave the way to successful shifts for fertilizer-based agriculture. Or alternatively, how past decisions can make the shift unfeasible.

2.4.2 Numerical analysis

2.4.2.1 Hypothesis

The effect of path dependence can be simulated from a simple computer model[30]. Two main principles are considered.

1. The age of fallow vegetation follows the process

$$F_i(t) = \begin{cases} 0, & if\ cut\ in\ t \\ F_i(t-1)+1, & contrariwise \end{cases}$$

2. The farmers always slash and burn the parcels covered with the oldest-aged vegetation, proceeding to the parcels covered with vegetation of the subsequent age, and so forth until a total land area equivalent to the pre-chosen extension for the cropping area is

[28] The term is used in the broad sense of processes where past decisions tend to create conditions that restrict present (and future) decisions, or “history matters”. See Liebowitz and Margolis (2000).

[29] As stated by Conrad (1999), “Numerical allocation problems can serve at least two functions. First, they can make theory and methods less abstract and more meaningful. Second, they can serve as a useful bridge from theory and general models to the actual analysis of ‘real-world’ allocation problems.”

[30] The software used is the NetLogo 5.0.2 (Wilensky, U. 1999 http://ccl.northwestern.edu/netlogo/ Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.)

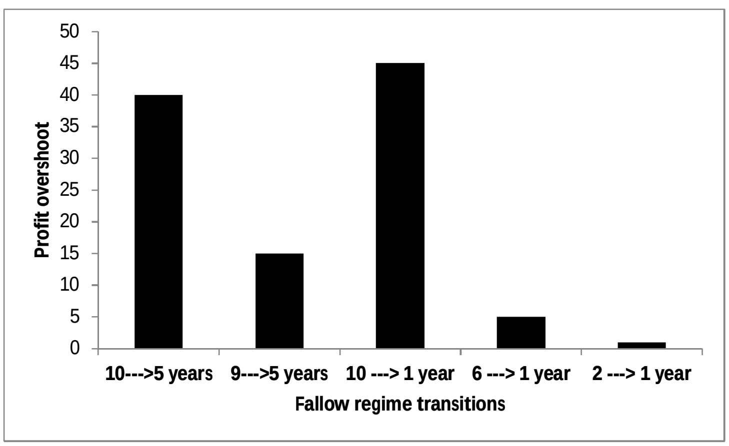
cleared (the age of the youngest vegetation is maximized under the restriction of meeting a goal for the total area cleared)[31].

Additionally, some simplifying assumptions are made. First, the function connecting fallow duration with crop production per hectare is linear: one additional year of fallow yields one extra kilogram of output per hectare. Second, only one crop is produced. And third, slash, burn and cultivation expenditures are normalized to zero and the price of output is normalized to one, what makes profit numerically equal to production (that's why the two terms will be used interchangeably henceforth).

In every period, farmers cut secondary vegetation in order to meet the pre-defined cropping area. This is the only action they implement, besides changing the fallow duration. It is considered a farm with 10 hectares allocated to fallow agriculture. Simulations start from the initial condition where a fallow of 10 years is practiced, what means that the area annually cropped amounts to 1 hectare.

2.4.2.2 Results

Figure 3 Profit overshoot for selected fallow regime transitions



From the simulations it is possible to have a measure for the impact of different levels of initial fallow over profit overshoots.

The longest fallow duration assumed, 10 years, is always the best starting point in what regards to the extra cash generated from the cropping of areas whose vegetation is above the new (and shorter) fallow period. But, for farmers that have not, in the recent past, oriented their decisions regarding fallow duration coherently to the goal of shifting to fertilizers, and,

[31] It is also assumed that, when more than one parcel is covered with the maximum current value for the age of secondary vegetation, the farmer slash-and-burn first the closest one.

suddenly starting considering this new route, the probability of being able to generate the money required from the conversion of over-matured secondary vegetation is small.
That's the case, for instance, of a farmer which currently crops five hectares per year and starts considering the reduction of fallow from six to one year ("6 → 1 year" transition): the profit to be earned corresponds to 1/9 of the value that could be obtained if a fallow of 10 years was currently practiced. Of course, the probability of raising money from profit overshoots gets further smaller for the farmers with shorter fallow durations: the transition from 2 to 1 year of fallow returns 1/45 of the value paid by the transition from 10 to 1 year of fallow.
Conclusively, the path dependence inherent to the fallow transition profit can be strong enough to make overdue shifts to fertilizers unfeasible. A *lock-in*[32] on fallow agriculture thus emerges even when unfavorable output price fluctuations and gradual learning of fertilizing techniques are both negligible. Public subsidies to machinery and inputs can prove insufficient to favor the breaking with fire-based methods. The abatement they provide can be not enough for the remaining cost of shifting to fit the capital of short-fallow practicing farmers.
To complete the analysis, it is interesting to speculate over the eventual effect of price fluctuations. The figures bellow present two alternative paths for going from a regime of 10 year fallow to 1 year fallow. A gradual transition from 10 year fallow to 1 year fallow, conducted with sequential reductions of one year in the cutting age, is illustrated on figure 4 and a less subtle transition, where fallow is taken from 10 to 5 years and, after this, from 5 to 1 year, is shown on figure 5.

Figure 4 Production/profit overshoots of the gradual transition to 1 year of fallow

[32] In the sense of Arthur (1989).

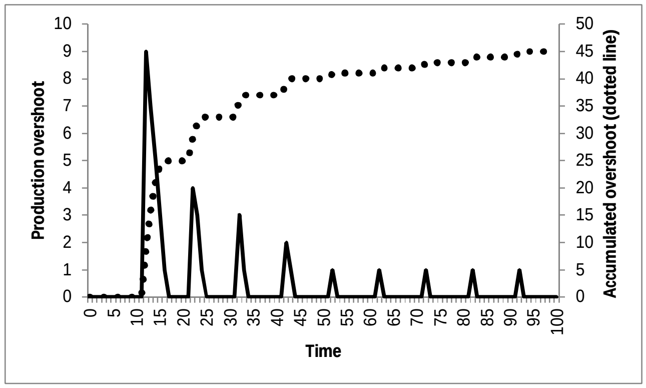
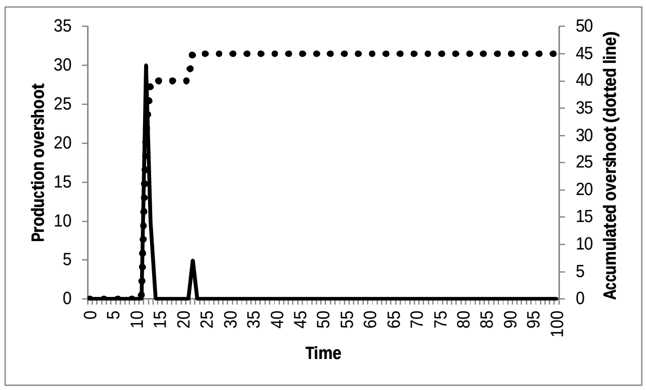


Figure 5 Production overshoots of the abrupt transition to 1 year of fallow



The overshoot of profit yielded by a transition between 10 year fallow duration to 1 year fallow duration is the same, no matter how gradual or sudden the transition is made: in both cases, the accumulated profit (dotted line, second vertical axis) is $45[33]. Such is the amount of the short-living natural capital represented by over-matured fallow stands. But, when output and input price variations are bring to analysis, the timing of the conversion into money becomes relevant.

Following the second path[34], the farm might end in a worst position if the price of output rises before he/she sells the last kilogram of crop grown on the last piece of land fertilized with 10-year aged vegetation. Now he has only 15 kilograms (45 minus 30)[35] of additional, "overshoot", production to sell for the new higher price, an amount which would be of 36 kilograms (45 minus 9) whether the gradual path was followed.

[33] This principle applies to all possible fallow shortening transitions, under the hypothesis assumed.

[34] According to standard resource economics theory (Conrad: 1999), the choice between gradual and abrupt depletion of the over-matured secondary vegetation resource depends on the user cost of depletion (Daly & Farley: 187), what incorporates a subjective discount rate (Conrad: 1999, p. 12).

[35] The simplifying assumptions guarantee that profit = production.

2.5 Conclusion

The tremendous cost of shifting away from fossil fuels has led some authors to the proposition that coal and petroleum extraction should be managed consistently with the goal to finance the investment on renewable energy sources (Ayres & Ayres: 2010, chap. 3). Similarly, cash-strapped S&BA farmers, that lack access to credit, have on the management of fallow shortening an opportunity to create a capacity to self-finance fertilizers and machinery. In both of the cases the resource (fossil carbon reserves and fallow vegetation) is conducted to a planned exhaustion in order to raise the money needed for paying the entry cost of the new technology.

The main point the paper brings on is that the path dependence on production overshoots can be managed in order to favor a successful transition to capital-and-input intensive agriculture. And, beyond that, such shift depends on an efficient management of the nutrient-land utilization trade-off, whose empirical relevance was attested for three municipalities of Pará State (the ones covered by RASDB, chapter 1 of this thesis and Gardner et al: 2013).

The sacrificing of the capital formed by over-matured vegetation, and also of the potential of the soil to give support to a vegetation that can later be used to replenish its fertility, two services for which farmers do not have pay for, must be proper valued by markets. What depends on a correct strategy to make the smallholders production reach the market for a reasonable price, avoiding congestion and coordination effects.

3 AGRICULTURAL USE OF FIRE IN THE BRAZILIAN AMAZON: ASSESSING THE ROLE OF NEIGHBORHOOD EFFECTS

Abstract

In the Brazilian Amazon, fire is still the most commonly used method to clear, prepare and fertilize land for agriculture. Short-term cost-benefit, even being a crucial determinant, can be, at least partially, compensated by the risk of damaging land allocated to income generating activities through accidental fires. The paper aims (i) to build a theoretical model, based on the theory of externalities, that describes how the spatial variation of the mentioned risk can make the private net benefit of fire use differ from the social net benefit; (ii) to test the hypothesis that such discrepancy can lead neighbor farmers to engage in Coasian bargains, and, thus, the risk imposed to land areas belonging to others is (at least partially) internalized by fire users. Simultaneity and omitted variable biases coming from interdependencies between land use decisions and fire use decisions are addressed with instrumental variables. It is argued that the slope of land parcels is an exogenous source of variation suitable for identification. Data comprises georreferenced farm boundaries, fire detections reported by MODIS satellite sensor and a land use map for Paragominas municipality. No evidence of internalization is found. In complement, own-areas under risk exert significant and negative effect over the likelihood of fire use. Transaction costs seem to be preventing formal or informal institutional arrangements for the sharing of accidental fire risk among neighbors to constrain individualistic behavior and promote socially optimal choice of locations to be treated with fire.

3.1 Introduction

In the Brazilian Amazon, fire is still the most commonly used method to clear, prepare and fertilize land for agriculture. The majority of agricultural fire use (AFU) can be divided into three categories, regarding the land cover converted. The first category, “deforestation fire” (Simmons et al: 2004), is characterized by the opening of new cultivation areas by the burning of primary or mature secondary forest. The second category, “fallow fire”, relates to the burning of secondary vegetation in fallow areas. The third possibility is the burning of old pastures to eliminate weeds and promote pasture renewal (Nepstad et al: 2001, Sorrensen: 2000 and 2004, Simmons et al: 2004, Arima et al: 2007, Barlow et al: 2012, Cochrane: 2009, p. 393).

Results from a number of research programs including Studies of Human Impact on Floodplains and Forests in the Tropics (SHIFT) and Alternatives to Slash and Burn (ASB) have demonstrated that the persistence of AFU cannot be attributed to the lack of technological alternatives (Denich et al: 2005, Tomich et al: 1998, Pollini: 2009). Vegetation can be removed manually using an axe or chainsaw or using tractors (Denich et al: 2004 and 2005, Börner et al: 2007). Fertilization of soil can be achieved using organic and/or chemical treatments (Denich et al: 2004 and 2005, Kato et al: 1999, Börner et al: 2007), and weeds can be managed both manually and with herbicides (Matos & Uhl: 1994, Tomich et al: 1998). Nevertheless these non-fire alternatives are more demanding in terms of both financial and human capital, tending to be, in short term, less economically rewarding (Nepstad et al: 2001).

However, short-term cost-benefit can be, at least partially, compensated by the risk of damaging crops, pasture, fences, infrastructure and machinery (Nepstad et al: 1999b, Mendonça et al: 2004, Bowman et al: 2008, Cochrane: 2009, p. 392) when fire goes out of control, spreading beyond the targeted location.

But do farmers really care about the possibility of generating an accidental fire when deciding where to burn?

The first step to address this question is to understand how the risk of accidental fires is related both with the private and with the social net benefit of fire use. For this, a theoretical model is built. It describes, based on the theory of externalities, how the spatial variation of the accidental fire risk, which is a function of the effective rent yielded by the land parcels that compose farms, determines whether is privately optimal and socially optimal to treat a parcel with fire.

The second step is to test the hypothesis that this discrepancy between the private and the social net benefit of fire use, in a given location, lead all implicated farmers to engage in Coasian bargains, and, thus, the risk imposed to land areas belonging to others is (at least partially) internalized by fire users.

The empirical analysis lays on georeferenced data on fire use, land use and farm boundaries, for the municipality of Paragominas (19,342 km^2) located in the east of the state of Pará, Brazilian Amazon. Paragominas was chosen as the study region to benefit from the in-depth survey data collected by the Sustainable Amazon research network (RAS in Portuguese, first chapter of this thesis), and the fact that it is unique compared to other Brazilian Amazon municipalities in having more than 80% of rural properties georeferenced (Martins & Souza: 2011, Viana et al: 2012, Neidemeier: 2011).

Next section presents the study region and the context prevailing in the year selected for analysis, 2010. The third section presents the theoretical model and the forth, the empirical methodology. The data is the subject of the fifth section, what is followed by the description of the estimation results. Implications for policy and for future research are addressed in the conclusion.

3.2 Study region

3.2.1 Development, deforestation and the greening of Paragominas

Settlement in northeast of Pará State gained momentum with the construction, in the 1960s, of a highway linking the State's capital, Belém, with the new national capital, Brasília (Veríssimo et al: 1992, Mattos & Uhl: 1994). Several new municipalities were then created, being Paragominas, founded in 1965, one of them (Pinto et al: 2009).

Cattle ranching was the main activity developed in the municipality up to end of the 1970s, when the subsidized credit dried out (Veríssimo et al: 1992). In 1990s logging became the "dominant economic force of Paragominas" (Veríssimo et al: 1992). In the booming period of the activity, more than 200 sawmills were in operation (Gerwing et al: 2000) and the municipality reached the first place of the national ranking of timber production in the year of 1990 (Pinto et al: 2009, p.13) with an output of 2.3 million cubic meters. From then on, production diminished, reaching, in 2007, nearly one fourth of 1990s level (578 cubic meters), owing to the exhaustion of the commercial timber stock available (Pinto et al: 2009, p.40).

The decline of logging was counteracted by the dynamism of agriculture, enhanced through intensification (rise in the average amount of output per area), and by the investment in mining of bauxite, made by Vale (Pinto et al: 2009), currently one of the main mining companies worldwide (Wilson: 2012).

Grain growing (especially rice, maize and soybean) and forest plantations had their economic relevance increased during the beginning of the XXI century. Soybean, a commodity mostly exported to other countries (Barona et al: 2010), covered a total area of 500 hectares in 1999 what increased to 10,000 hectares in 2006 (IBGE: 2013).

The last four paragraphs presented some of the main features of the development model historically adopted by Paragominas. Its social costs, imposed by the suppression or disturbance of forests covering an area of 878 hectares (45% of the municipalities' area) have also to be emphasized. It was for the lack of environmental concern, in this particular sense, that Paragominas' model of development was put into question in the year of 2008, when Brazilian national deforestation policy shifted from federal-level centralized command-and-control measures to more decentralized and incentive-based measures (Assunção et al: 2012).

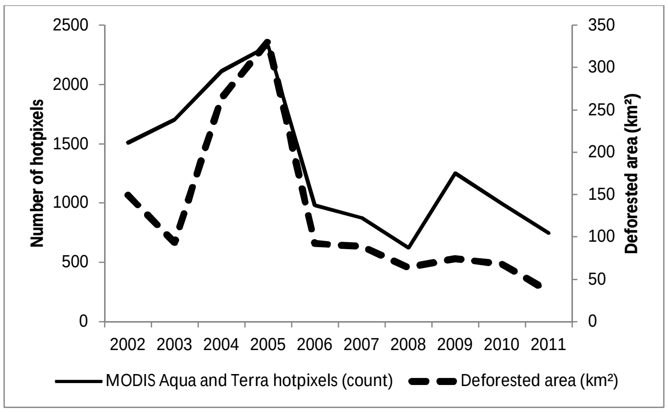
The municipalities that concentrated the largest fraction of the recent illegal deforestation were elected as the targets of the new deforestation policy (Assunção et al: 2012). In consistency with this orientation, the National Monetary Council[36], introduced a resolution that made, from July 2008 on, the concession of credit conditional upon the presentation, by the borrower, of evidence of compliance with the environmental code (Assunção et al: 2012). What, for rural Amazonia meant the rationing of credit for owners of farms that have being deforested beyond the limit fixed by law (50% or 80%, depending on the region, of the whole land area). A black list of deforestation, exposing, to the world, the top municipalities in the Amazonian ranking, was also created, menacing the reputation of agricultural commodity exporters as Paragominas (Brito et al: 2010, Guimarães et al: 2011, p.10).

The policy innovations quickly reverberated into reactions of rural producers and of their political allies. It is exactly as one of these responses that the "greening" of Paragominas emerged (Brito et al: 2010, Guimarães et al: 2011, p.10). But, in this particular case, as a pro-active initiative, comprising the promotion of sustainable land uses and a pact of zero deforestation (Brito et al: 2010). The joint work of players from the public, private and third sector resulted into the reduction of deforestation rate to 21 km²/year at the end of 2009 (Brito et al: 2010, figure 6 below) and the georeferencing of 83% of the municipalities' land area under private ownership (rural properties) up to March 2010 (Brito et al: 2010). With this, Paragominas was officially excluded from the black list of deforestation in April 2010.

[36] The institution that regulates the Brazilian monetary and financial systems.

It is however, not clear yet, whether and how fire use was affected in its importance as an agricultural practice and in what regards to the risks imposed to local society and to local and global[37] environment - figure 6 reveals a decreasing trend for fire detections from 2009 on. The paper aims to contribute for the clarification of this question, looking to a specific dimension of fire use, namely the sharing of the risk of accidental fires among collocated farmers. The analysis focuses the year of 2010, the most recent year for which data on land use could be obtained.

Figure 6 Fire use and deforestation in Paragominas, 2002-2011



Source: INPE (http://www.dpi.inpe.br/proarco/bdqueimadas/) and PRODES (http://www.dpi.inpe.br/prodesdigital/ prodesmunicipal.php)

3.2.2 Fire use in post-greening Paragominas

Cattle ranching is one of the main primary activities of the municipality (Pinto et al: 2009). It is connected with fire through the conversion of primary forest into pasture and through clearing of overgrown pasture taken over by secondary vegetation (Cochrane: 2009, p.393, Mattos & Uhl: 1994, Pinto et al: 2009, p.35, Mendonça et al: 2004, p.89). Even being that the first use of fire has been dramatically reduced after the pact for curbing deforestation, on field interviews with members of key institutions, done in 2012, point out to the prevalence of the second motivation[38]. A survey conducted in 2011 and 2012, with Paragominas' farmers provides further corroboration (see table 1.3 on the first chapter of this thesis).

[37] Given the implications for global warming coming from burning of vegetation and/or degraded pasture.

[38] This piece of evidence comes from semi-structured interviews, covering fire use motivations, practices and accidental fires, conducted (from 19 to 21 March 2012) with (i) the head of the rural workers' labor union (which represents small to medium familiar agricultural producers); (ii) the head of the association of workers and agricultural producers of an agrarian settlement, located at the northeast of the municipality and; (iii) a researcher of the Brazilian Agricultural Research Corporation (EMBRAPA, federal government), mainly occupied with rural extension for cattle ranchers.

Slash and burn agriculture has also been (Pinto et al: 2009, p.36) and still is a relevant vector of fire use in the municipality, being practiced mostly by small farmers (land area not above 100 hectares) located into agrarian settlements planned by the federal government or on untitled land (Sorrensen: 2009, Pinto et al: 2009, p.36-37, Barlow et al: 2012). What is, again, confirmed by field work[39] and by the aforementioned survey (first chapter of this thesis).

Therefore, the fire that can be detected from satellite data on Paragominas territory, the information source in which the paper lays, is restricted, considering the post-greening period (which includes 2010), to the conversion of degraded pasture or fallow.

3.3 Theoretical model

3.3.1 Conceptualizing the externality of accidental fires

That accidental fires can induce several damages is sufficiently stressed in the literature (Mendonça et al: 2002, Nepstad et al: 1999a, Cochrane: 2009, p.392, Alencar: 2005). But the damage in itself is not necessarily the more enlightening way, regarding both policy formulation and theoretical treatment, to apprehend the nature of the externality of accidental fires.

The uncontrolled flame is an externality, in the sense of Baumol & Oates (1988, chap.3, sections 1 and 8): it starts as a byproduct of land management decisions made by a farmer and ends as a shock to the production functions of neighboring farmers (that have not taken part on the decisions that generated it). When the unexpected fire destroys crops, pasture, trees, and whatever it finds on its way, it instantaneously reduces the level of output generated from the amount of factors employed by neighboring farmers.

But even if fire does not, effectively, runs out of control, causing real losses, production functions can, theoretically, be shifted. In fact, the mere probability of being hit by an accidental fire is sufficient for changing the production function of farmers. This is so because rational agents that frequently observe fire use on the proximity of their farms, will start considering the possibility of having their production accidentally burned[40]. Uncertainty

[39] The actors referred in the previous note also mentioned slash and burn as a vector of fire use as well as the following additional actors: (i) one of the members of the team of rural extensionists of the Pará State enterprise of rural extension; (ii) the rural extensionist named by the Paragominas municipality agriculture department as the responsible for the agrarian settlement visited; (iii) ten (of fifteen interviewed) agricultural producers that live on the agrarian settlement visited (only two of the ten reported not to use fire, but reported to have observed fire use by their neighbors).

[40] This statement comes from the direct application of the principle that rational agents incorporate, to their decision making, the risks they face – provided that the risks really matter for the decisions to be made (the principle is in accordance with the behavior of rational agents in the context of general equilibrium under uncertainty, see Mas-Collel et al: 1995, chap.19). The empirical/concrete validity of the statement is a matter that is left for chapter 4.

regarding this possibility creates a decision making environment where the agent does not know from the start how much output he/she will obtain from a given number of labor hours, machine hours and kilograms of fertilizer applied to a parcel. All he/she knows is the expected output value.

Disregarding additional sources of uncertainty, the expected level of output, associated with each vector of factors (and inputs), is negatively related with the probability of accidental fires. The level of this probability faced by a farmer depends on how, where, when and how intensively or frequently fire is used by the neighboring farmers. Conclusively, on a purely theoretical ground, the fire use decision of a farmer shift the expected production function of neighboring farmers, as a byproduct. What allows for claiming that the externality it gives place, the risk of accidental fire, is, in a context of economic choice under uncertainty, a genuine technological externality (Baumol & Oates: 1988, chap.3, sections 1 and 8)[41][42].

Under such conception, the externality is not the accidental fire in itself, but the risk or probability of accidental fire. Or, alternatively, the risk of losing production through an accidental fire. Let the focus be set on the issue of the location of fire use. A farmer, deciding where to burn, can raise the risk of losses through accidental fires his/her neighbors face if the spot chosen is too close to the farm boundaries. The level of risk "consumed" by neighbors will rise and, consequently, their expected levels of output will fall for all possible combination of production factors.

One crucial characteristic of the externality is its limited reach. It makes sense to state that the risk of a spot being reached by an accidental fire decays with the distance from the point in space where fire is set[43]. Beyond a maximum radius, the risk fades to zero. This is a

[41] The foundation of the uncertainty lies on the fact that an accidental fire is only certain after it has occurred, but its impact can be (presumably) detrimental enough to ask for preventive measures.

[42] The area of a farm – or the set of parcels - invaded, and, thus, damaged, by uncontrolled fire is a random variable such as the level of pollution consumed in a given location when the dispersive power (velocity) of wind varies randomly in time. This analogy comes from the example of externalities subjected to uncertainty worked out by Baumol & Oates (1988, chap.19, section 5).

[43] The evidences for the spread of accidental fires on Brazilian Amazon report radius of reach of 4 km at most (Mendonça et al: 2004, Alencar et al: 2005, Nepstad et al: 1999a; see section 3.5.2). The core of the model of fire spread used by the National Fire Danger Rating System of the United States consists in a seminal fire spread model elaborated by Richard C. Rothermel in 1972 (Scott & Burgan: 2005, p.1). This model (whose dependent variable is the fire spread rate, measure in meters/ minutes) sustains that the factors that influence the spatial spread of fire are: (i) wind speed and direction (Quintiere: 2006,p.191, Rothermel: 1972,p.34); (ii) moisture (Rothermel: 1972, p.34), (iii) topography (slope, specially, Rothermel: 1972, p.29, p.34); (iv) quantity of fuel (timber on trees, leafs and trunks on the ground, etc) and fuel moisture (timber on trees or on constructions, for instance, logging slash, etc., Rothermel: 1972, p.28-29, p.34). Cochrane (2009, p.46), describing the model states that the "most dynamic" determinants of the spread rate are (i) the wind and; (ii) the moisture content of fuels found by fire during its path of propagation. This means that these two natural factors can act to increase or to limit the area burned, depending on how they change in space and time during the fire spread – as Cochrane

significant difference in relation to the conception of air pollution that is generally employed to motivate the analysis of general equilibrium under uncertainty (Baumol & Oates: 1988, chap.4). And that is because of the assumption that polluters can spread freely along space, with negligible attrition[44]. This is part of the reason why air pollution is generally the textbook example of a successful application of the Pigouvian tax: as Baumol & Oates (1998, chap.3, section 10) make it clear, this intimately depends on the implicit assumption that the number of consumers of the externality is large.

Contrariwise, the number of consumers of the accidental fire risk externality is small and does not go much farther than the neighbors that share boundaries with the farm where the fire was started[45]. Therefore, the externality under study fits what Baumol & Oates (1988, chap.3, section 10) call the "small numbers case", and the main implication is that the classical solution of a Pigouvian tax cannot be laid on to implement, through a market mechanism, the Pareto-efficient level of accidental fire risk[46].

Nevertheless, the alternative approach of "Coasian property-rights" is a possible way to reach the social optimal level of generation of the accidental fire risk externality (Baumol & Oates: 1988, chap.3, section 10). This possibility is explored on the next subsection, where the level of risk of accidental fires is measured not in terms of the expected production levels of the neighboring farmers, but in terms of their expected land rent.

3.3.2 Two-farm unidimensional Coasian bargain model

3.3.2.1 Farm's representation

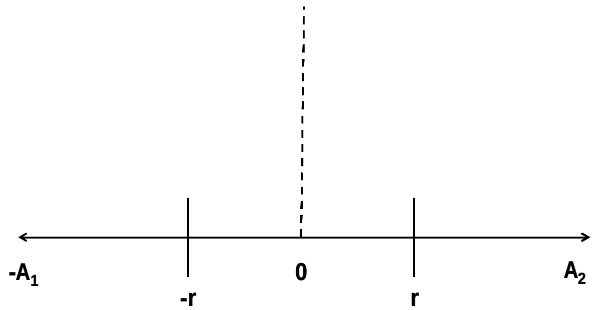
(2009, p.398) observes for the case of Amazon Forest, "Fire progression slows as fuel moisture levels rise". In the Amazonian biome, moisture tends to be one of the main forces that restrain fire propagation (Nepstad et al: 2001; Cochrane: 2009, p.398).

[44] What is not always realistic, given the influence of topography, wind velocity, temperature, and other factors, on pollution dispersion.

[45] Is this externality a private bad or "depletable" externality (Baumol & Oates: 1998, chap.3, section 2)? Or, what turns out to be the same, does the level of risk consumed by a neighbor reduces the level available for the consumption of other agents? Yes. The maximum radius of reach of a fire, started in a given point in space, has a finite length. It, thus, spans a circular region of finite size in the space, within which uncontrolled fire can spread. The larger the share of the region of spread that belongs to (is overlapped by) a farm, the greater the amount of risk the owner of such farm consumes and the smaller the amount that remains to be consumed by other farmers. So the externality is "divisible among [potential] victims" as it is the case of trash dumped by an individual on private unguarded property belonging to other individual(s) (Baumol & Oates: 1988, chap.3, section 2).

[46] Besides, such solution is impractical, given that the calculation of the tax requires the estimation of the risk each fire-user farmer expose his/her neighbors to (such being the social damage created). What, in practice, can be very difficult.

Figure 7 Two-farm unidimensional model*



*the dotted line indicates the common boundary of farms

Let us focus on the interactions between two farmers, 1 and 2, in a period where farmer 1 is choosing where, within his farm, to use fire. The only passive victim of an eventual accidental fire is farmer 2, the only neighbor of farmer 1. In a one-dimensional world, a farm takes the form of a line segment and the locations or parcels in which it can be broken down are nothing but points. Figure 7 represents the two adjacent farms over a Cartesian one-dimensional line with the origin set exactly on the point that corresponds to the (unidimensional) border of farms, the only point shared by the properties.

Agent's 1 farm is located on the negative segment of the line, being its size given by the length A_1. I.e., it coincides with the segment [$-A_1$;0]. Agent's 2 farm corresponds to the positive segment [0;A_2].

It is possible to divide each farm into two zones, a "risky" and a "risk-free" zone. For this it is necessary to assume a fixed pre-determined maximum radius of reach for accidental fires, r. Agent's 1 fire, no matter in which point inside of his farm it is started, can only posit a threat to land uses within a distance of r kilometers. This means that, if agent 1 starts a fire r km away from the border (the origin), he/she will expose agent 2 to no potential harm. But, if a fire is set less than r km away from the border, land uses developed by agent 2 can be potentially hurt.

From this observation, one concludes that agent's 1 fire use is harmful for agent 2 only if it takes place in the segment [-r; 0], that will be called, hereafter, the "risk transfer" segment of agent's 1 farm.

Any fire started within such segment can cause harm within a distance of r kilometers. What is, then, the segment of agent's 2 farm under the risk of being invaded by uncontrolled fires started by agent 1? The point within agent's 1 farm which is closer to agent's 2 farm is the border (origin) – it is, in fact, inside agent's 2 farm. Therefore, only the segment [0; r] of agent's 2 farm is under the hazard of being accidentally burned by agent 1. The parcel r is the farthest point in space that can be reached by an accidental fire deriving from agent's 1 land management. Only when the last agent burn exactly the border point it is plausible to think about an accidental fire getting that far.

The segment [0; r] will be called the "risk taking" segment of agent's 2 farm.

Besides the risk transfer and the risk taking segments, that are two additional segments, $[-A_1;-r]$ and $[r; A_2]$. The first one, located within agent 1 farm, can be treated with fire without harming agent 2. Only land uses developed by agent 1 are at stake within such segment, what is also guaranteed by the implicit (simplifying) assumption that there is no farmer managing the segment $[-\infty;-A_1]$. The segment $[r; A_2]$ is where agent's 2 land uses are free from the risk of being burned by fires coming from the neighboring farm.

3.3.2.2 Land use change and the incentive to use fire

Fire is a tool to convert land from the current to an alternative land use. The opportunity for land use change arises when parametric shocks, generally price changes, raise the level of the potential rent that can be obtained from a land parcel beyond the level of the rent effectively generated in the current period[47][48]. This sudden discrepancy has to be more than enough to cover the land conversion cost, otherwise, land would not be converted, even if it can yield a higher level of rent. In short, there will be incentive to convert parcel i to an alternative land use if and only if: potential rent at i > effective rent at i + conversion cost at i. A condition that can synthetically be written as $\pi_i^* > \pi_i + c_i$.

This principle can be illustrated with three examples that correspond to the main reasons for which fire is used by Amazonian farmers. When the potential rent of a parcel (opportunity cost) currently covered with primary forest becomes greater than the effective rent delivered by this land use, it pays off to deforest the parcel, opening space for the growing of crops, the raising of cattle and to other land uses. But only when the cost of turning forest into such land

[47] This statement is inspired in parcel level microeconomic models of land use choice pioneered by Chomitz & Gray (1996). A clarifying presentation of these models can be found in Nelson & Geoghegan (2002). Under a discrete choice perspective, the agent lays on the choice rule that consists on picking, for each and all parcels, the land use that yields the largest present value of the prospective flow of profits, or land rent. The opportunity cost or potential rent, in this case, is the land rent yielded by the non-developed land use which yields the largest rent. In equilibrium- i.e., in the situation where the agent has no incentive to replace the land use currently developed in a parcel -, the rent yielded by the current land use, or the parcel's effective rent, is no smaller than the potential rent (or opportunity cost). When exogenous parameter shocks occurs, i.e., price changes - it is assumed that farmers are price-takers – land uses that are not developed in a given parcel can have their rent raised, and thus, the potential rent of such parcel can suddenly surpass the rent yielded by the land use currently developed. A potential incentive for replacing the current land use arises, depending on how costly this replacement is.

[48] If the price of cattle rises, the effective and the potential rent yielded by a parcel currently allocated to cattle raising will both raise and in the same amount. No opportunity for land use change will be created on these parcels. But, the opportunity will arise on all parcels allocated to other land uses, assuming that only the price of cattle rises.

uses does not fully compensate the rise in the rent. Two examples that are more pertinent for the case of smallholdings are of land parcels covered with fallow vegetation and with degraded pasture. When the effective rent generated by fallow land[49] is surpassed by the potential rent, it pays off to convert, depending on the cost of slashing and clearing. The case of pasture overrun by weeds is similar: beyond a certain level of weeds accumulated per hectare, the effective rent is virtually zero.

A potential rent above the effective rent is a necessary ($\pi_i^* > \pi_i$), but not sufficient condition for conversion. Nevertheless, such condition is of special interest given it is only for parcels that verify it that the possibility of fire use arises[50]. To differentiate such parcels from the rest, a formal notation will be introduced. Let an unidimensional farm be divided into parcels of infinitesimal length, or points, represented by the subscript i, $i \in I$, where I is the complete set of farm parcels. Let, also, the subset of parcels of the farm whose potential rent is suddenly set – by exogenous price variations - above the effective level be represented by X, $X \subseteq I$ - "$\subseteq$" stands for "is contained by" or "is a subset of". An element of the last set will be denoted by the subscript x ($x \in X$).

A necessary condition for fire to be chosen at parcel x, is that it proves itself the least cost land conversion method among all the available options, which generally include, additionally, manual methods (such as axe and/or a chainsaw) and mechanized methods (tractors). What means that the conversion cost has to be minimized through the proper choice of the conversion method. The general and sufficient condition for fire to be chosen – a binary and thus, discrete, choice – is, twofold:

$$(C1)\delta_x + \mu_x + \int_F f(z)g(z)dz < \widetilde{\delta_x}$$

$$(C2)\delta_x + \mu_x + \int_F f(z)g(z)dz < \pi_x^* - \pi_x$$

Where δ_x is the cost of converting parcel's x through fire and $\widetilde{\delta_x}$ is the cost of the least cost alternative land conversion method. Formally, $\widetilde{\delta_x} = \min\{c_1,\ldots,c_{x-1},c_{x+1},\ldots,c_M\}$, being c_i, $i \neq x$, the cost of i-th of the M-1 land conversion methods besides fire. The cost of preventive measures to avoid accidental fires - firebreaks, burning against the wind, etc., (Bowman: 2008

[49] Given by the value of fertilizers economized through the conversion of vegetation into ashes (chapter 2 of this thesis).

[50] Parcels that will not be converted (i: $\pi i^* \leq \pi i$) cannot be the object of the choice over the method of conversion.

and Souza: 2009, table 3-3, p.58) - is denoted by μ_x. The integral gives the total value of the loss that is, even under a non-zero investment on preventive measures, expected to be imposed by accidental fires. The domain of integration, F, $F \subseteq I$, is limited by the maximum distance from point x that can be reached by an accidental fire, i.e., F = [x –r; x+r]. The function f(z) gives the effective rent yielded by parcel (point) z, while g(z) is the probability that parcel z get accidentally burned[51].

While the first condition (C1) requires that fire is the least cost land conversion method, the second (C2) requires that its cost is below the return of conversion, given by the difference between the potential rent and effective level currently yielded by parcel x.

The monetary cost of an accidental destruction of the land use currently developed at parcel i is given by the effective rent yielded by the parcel – a 100% loss is assumed. Fire can reduce the potential rent only if it causes an alteration of the biophysical features of the parcel's land - killing soil biota, for instance, Cochrane (2009, p.47) -, thus imposing a reparation cost to the farmer. For the sake of simplicity, this possibility will not be considered here.

One difficult question that arises is whether the parcels within the reach of accidental fire whose effective rent is below the effective level have to be considered when accounting for losses. Given that some of them will be converted, it seems not appropriate to define their accidental burn as loss. Nevertheless, this task turns out to be impossible owing to its tautological nature: to know whether it pays-off to convert parcel x through fire it is necessary to know which parcels within a distance r of parcel x will also be converted, but, to know that, it is necessary to know which parcels within a distance r of each parcel r km away from x, what does include x, will be converted. Thus, to know whether it pays-off to convert parcel x through fire requires knowing whether it pays-off to convert parcel x through fire or other method.

There are two coarse criteria that avoid the tautology. The first consists in accounting all parcels within the radius of reach of a fire as representing potential losses of effective rent, being their effective rent below or not the potential level. This is a conservative criterion, which overestimates the loss, because potential harm to parcels that will be converted is accounted as part of the loss. The second criterion consists in excluding the parcels that yield an effective rent below the potential, i.e., parcels for which there is a potential incentive to convert are assumed not to represent a loss whether accidentally burned. The accidental burn

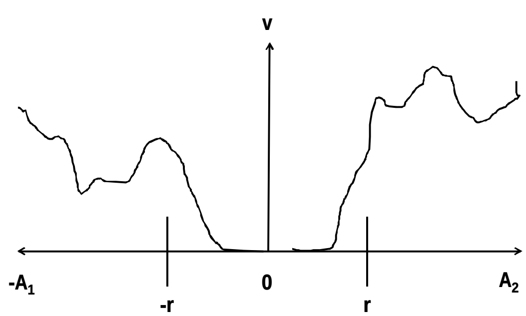
[51] The value f(z)g(z) is a measure for the risk of accidental fires faced at parcel z.

of parcels that will not be converted is thus disregarded, so the loss is underestimated by the second criterion.

The first criterion will be adopted because the complication introduced by the second one, which requires the exclusion of some parcels in the interval F = [x –r; x+r], is not compensated by a gain in terms of consistency with economic rationality, quite the contrary. If, to choose among a set of technologies, the agent lays on a choice rule that systematically underestimates the cost of only one technology (fire, in the case here), he/she can be led to choose this technology (fire) not because it is the least cost option, but because its cost is being underestimated.

By incorporating, with a vertical axis, the effective rent generated by each and every point (or unidimensional parcel) of the two farms of the unidimensional model - a measure for the economic value under risk of being destroyed by fire -, the spatial distribution of such metric can be illustrated by a diagram such as the one in figure 8.

Figure 8 Spatial distribution of the effective land rent (v = f(x)) across farms



3.3.2.3 The externality of potential losses imposed by accidental fires

Let it be assumed that there is a parcel x*, x* ∈ X, which is located within the risk transfer segment of agent's 1 farm i.e., x* ∈ [-r; 0], and, additionally, that verifies conditions C1 and C2. I.e., it is true that:

$$(C1^{*})\delta_{x^{*}} + \mu_{x^{*}} + \int_{x^{*}-r}^{0} f(z)g(z)dz < \widetilde{\delta_{x^{*}}}$$

$$(C2^{*})\delta_{x^{*}} + \mu_{x^{*}} + \int_{x^{*}-r}^{0} f(z)g(z)dz < \pi_{x^{*}}^{*} - \pi_{x^{*}}$$

The crucial detail lies on the upper limit of the integral, which is zero and not x* + r. The reason is that, given that – r < x* < 0, the right hand limit for the reach of an accidental fire spread, x* + r, has to fall on the interval – r + r < x* + r < 0 +r, i.e., 0 < x* + r < r. But agent 1, as a self-interested rational being, has no reason to care about parcels that are located after the origin. They are left for their owner, agent 2, to worry about. Therefore, the right limit of the radius of reach of accidental fires is "censored" at x* + r = 0, and so, consequently, the upper limit of the integral.

The private net benefit (PNB) of converting the parcel x* through fire can be measured by the following expression:

$$PNB = \Pi_{x^*} - \int_{x^*-r}^{0} f(z)g(z)dz$$

Where $\Pi_{x^*} = \pi_x^* - \pi_x - \delta_x - \mu_x$. Thus, the return for agent 1 is given by the rise in the rent yielded by parcel x*, net of the conversion cost. Analogously, the social net benefit (SNB) is given by:

$$SNB = \Pi_{x^*} - \int_{x^*-r}^{x^*+r} f(z)g(z)dz$$

The main specificity of SNB is the fact that it accounts for the expected loss caused by accidental fires considering the effective rent generated by all parcels within the radius of reach of an accidental fire started at x*, no matter who owns the parcels. It is exactly the net benefit that would be obtained if the two farms were managed by a single farmer.

It can be concluded thus, that:

$$SNB = PNB - \int_{0}^{x^*+r} f(z)g(z)dz$$

What also implies that SNB ≤ PNB, given that the integral, being the absolute value of an expected loss, is always positive. Such integral will be hereafter symbolized by "ELT", what stands for "expected loss transfer"[52].

Now, it is possible to establish the fundamental result of the theoretical model just built. The effective rent paid by agent's 2 parcels located in the segment [0; x*+r] can be high enough to make the treatment with fire of parcel x* not optimal whether the two farms were owned by the same agent. And, even being that, under the case of two separated owners, it is optimal for agent 1 to use fire. I.e., assuming that C1* is satisfied, it is possible to have PNB > 0 and SNB < 0. This is what happens when PNB < ELT, i.e., the expected loss that a fire started by agent

[52] A measure for the risk transfered from the agent to their neighbors.

1 at parcel x* imposes (or transfers) to agent 2 is no smaller than the net benefit obtained by agent 1[53].

In such situation, the burning of parcel x*, even being privately optimal for agent 1, is not optimal from the social standpoint. What is a consequence from the fact that, "society" means, in the simplified framework here adopted, agents 1 and 2. Being, thus, the expected loss faced by one of the agents larger than the benefit obtained by the other, the decision that creates such state of things cannot be socially optimal.

The good news is that there are Coasian bargains (in the sense Baumol & Oates: 1988, chap.3, section 10 and Coase: 1960) that can lead "society" to the optimal solution if agents are let free to engage in costless negotiation and either the right to use fire, or the right to be protected from fire used by others, is guaranteed by law.

Assuming that agent 1 has the right to use fire and agent 2 does not have the right to be protected from fire used by his/her neighbor. In this case, it pays off for agent 2 to offer agent 1 an amount of money not superior to the expected loss incurred by agent 2, ELT. But, for agent 1 to take it, such offer must surpass the net benefit obtained from the burning of parcel x* (PNB). Given that PNB < ELT, the agreement is feasible and agent 1 will not use fire.

Now, if agent 2 has the right to be (fully) protected from the fire used by his/her neighbors, it is agent 1 that has to make a payment, now, as a (anticipated) compensation. The problem is that this agreement is not feasible, given that agent 1 have no incentive to pay a value that is larger than PNB. But this upper limit is below agent's 2 expected loss, ELT, given that PNB < ELT. What will happen is that, when the right of agent 2 over fire protection is fully enforced by the environmental authority, it does not pay off for agent 1 to use fire.

It results that, as Coase theorem proposes, it does not matter who has the property right, the social optimal decision, which is not to use fire on parcel x* (given that SNB <0), will prevail, when the cost of reaching an agreement is negligible.

A few words on the concreteness of the bargains just discussed are needed. The right of being protected from fire is consistent with the Brazilian law of controlled burning (IBAMA: 1998). It establishes that the requisition of a license for treating land with fire is mandatory, what presupposes the demarcation, by the requester, of the area to be treated with fire (IBAMA: 1998). This information is registered on the license. The violation of such area is a fault for which the agent must indemnify the eventual victims, i.e., those, among his neighbors, whose

[53] The case where SNB = 0, i.e., PNB = ELT, is trivial. Society will be indifferent from treating parcel x* with fire or not and, thus, if agent 1 has incentive to use fire, this decision cannot be claimed to be non-optimal from the social standpoint.

farms were invaded by flames. Besides that, damage to the environment must be compensated, for instance, by the recomposition of forests (IBAMA: 1998).

Some evidences suggest that the compliance with the controlled burn law is limited on Brazilian Amazon (Souza: 2009, chap.2, TCU: 2000, p.25, chapter 1 of this thesis, table 1.4). But this, nevertheless, does not prevent neighbors from establishing informal agreements for sharing the risk of accidental fire. As the model proposes, potential victims always have incentive to act for preventing damages imposed on them whether these damages are non-negligible.

The engagement on informal agreements with neighbors can be conceived as a preventive measure - besides, of course, building firebreaks (Bowman et al: 2008) - as argued by Simmons et al (2004, p.85) and Nepstad et al (1999a, p.108) and evidenced by the fieldwork conducted by the latter authors (p .108-114), by Cavalheiro (2004 chap.4), and more recently by Bowman et al (2008) and Souza (2009, chapter 3). An additional evidence lies in the fact that, among the 256 farmers who used fire in 2009 or later, sampled by RASDB, 201 (78%) stated that they use to warn neighbors before burning.

Informal agreements regarding the use of fire are institutional arrangements[54] to manage its use in a collectively satisfactory way (Souza: 2009, chapter 3), the same way the controlled burn law and the institutional apparatus mobilized for monitoring its compliance is a institutional arrangement, although formal. The informal agreements exert a restrictive influence over farmers' behavior of the same nature that would be exerted whether the controlled burn law was enforced by environmental authority, leading, thus, to the (at least partial) internalization, by fire users, of the expected losses they impose on others.

A clarification is needed. It is not the goal of the paper to seek for evidences that allow for identifying which institutional arrangement, the formal law or informal agreements, are adopted in practice.

The goal is to seek for evidences that neighbors, no matter the institutional arrangement that govern their interaction, interact, that is, bargain, somehow, in order to share accidental fire risk. What is equivalent, in basis of the model proposed, of stating that farmers internalize, at

[54] As defined by Davis & North (2008 [1971],p.7): "An *institutional arrangement* is an arrangement between economic units that govern the ways in which these units can cooperate and/or compete."

least partially, the risk of accidental fires they would fully transfer to their neighbors[55], whether no institutional arrangement existed to constrain their individualistic behavior.

3.3.3 The hypothesis to be tested

The hypothesis that comes as an outcome of the theoretical model is:

(H) The effective income yielded by the land uses developed by neighboring farmers within a distance equivalent to the radius of reach of fire exerts a negative causal influence over the likelihood of the farmer to treat a given parcel x with fire.

There are three conditions that, together, are necessary and sufficient for the validity of hypothesis H:

(1) The use of fire in parcel x is optimal for the farmer that owns it;

(2) The use of fire in parcel x would not be optimal if the farmer and all his/her neighbors constituted a single decision making unity (i.e., social optimality is violated);

(3) Neighboring farmers engage in costless bargains, governed by formal or informal institutional arrangements, to share the risk of accidental fire spread.

First condition is assumed to be fulfilled for parcels treated with fire, since it is not part of the goals of the paper to seek evidences that agents behave rationally in the individualistic sense. Therefore, to test hypothesis H is an indirect way to know whether conditions (2) and (3) are empirically plausible, i.e., whether farmers engage in Coasian bargains when this proves to be optimal from their collective standpoint.

Next section presents an econometric model for submitting H to refutation.

3.4 Empirical method

3.4.1 Reduced form model and proxies for covariates

Let the land area of a farm be divided into locations delimited by the overlapping of a map registering farms' boundaries with a grid of squared cells of a fixed size (figure 9). Two classes of "polygonal locations" are thus obtained: (i) interior-perfectly-squared-shaped-polygons (A on figure 9) and; (ii) border polygons whose shape is molded, overall, by the outline of farm boundary (B on figure 9). Pieces of land belonging to these two classes are, in what follows, referred as "land parcels", or, synthetically, "parcels".

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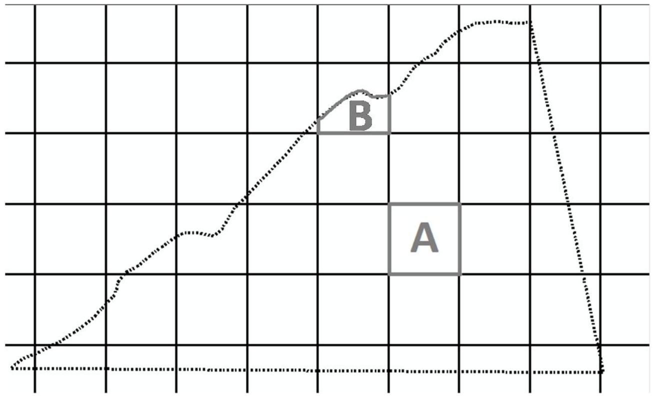
[55] ELT in the theoretical model. In this point of the reasoning it is necessary to remind that the part of expected loss (the measure for risk adopted in the theoretical model) related with land parcels that belong to the agent are not object of transfer.

Figure 9 The concept of land parcel*



*The outline of the farm is indicated by the dotted line and the cells of the grid by the solid black lines.

As proposed by the theoretical model, the private benefit, or pay-off, of fire, conceived as a tool for converting the land cover of parcel "i", is given by:

$$PNB^{e}_{i} = \Pi(LC_i) - E(L_i) \quad (1)$$

Where $\Pi(LC_i)$ is the return of the land conversion, in terms of the foreseen increase on effective land rent, net both of the cost of conversion through fire and of the cost of preventive measures to avoid accidental fire spreads. It is assumed that such magnitude is solely determined by peculiarities of the land management techniques under choice (i.e., fire and alternatives) and by the land conversion developed.

$E(L_i)$, a non-negative variable, is the expected monetary value of losses caused by accidental fires (Sorrensen: 2000, Bowman et al: 2008)[56]. In order to test the hypothesis of internalization, $E(L_i)$ must include not only the expected loss of agent's own-effective-land-rent, $E(I_i)$, but also the expected cost for the agent of imposing rent losses to others, $E(I^*_i)$[57].

What requires the following reformulation of equation (1):

$$PNB^{e}_{i} = \Pi(LC_i) - E(I_i) - E(I^*_i) \quad (1')$$

For a rational agent, fire is the best land conversion tool at parcel "i" as long as its pay-off is positive, what means that the return of land conversion through fire is more than compensated by its cost, the last term incorporating losses eventually imposed by accidental fires. To move further, the parametric assumptions below are needed.

[56] "Because fallows are considered abandoned unused areas, farmers may not take preventative measures when burning near them, and as such, these areas become susceptible to accidental fire (Sorrensen: 2000, p.17)". "Only slightly over a quarter of households interviewed said they take preventative measures [to prevent accidental fires] , such as clearing fire lanes, and usually only in specific cases when burn sites bordered pasture, cropland, neighbor's fields, or house sites (Sorrensen: 2000, p.19)."

[57] The term PNB, defined in the theoretical model, includes at least part of the term ELT, when institutional arrangements restricting selfish behavior do exist.

$$\Pi(LC_i) = \alpha_1 + \beta_1 LC_i + e_{1i} \ (2)$$

$$E(A_i) = \alpha_2 + \beta_2 A_i + e_{2i} \ (3)$$

$$E(A^*_i) = \alpha_3 + \beta_3 A^*_i + e_{3i} \ (4)$$

The vector LC_i comprises the areas allocated to four land use categories, crops (annuals and perennials), pasture, forest plantations and forest (primary and secondary), what is a proxy for the return of land use change at parcel "i".The term e_{1i} captures non-observables through which the proxy can affect the cost-differential of fire use - fire-sensitiveness, for instance, tend to vary among crops, what cannot be accounted for with data that do not distinguish crop varieties.

Coherently with the theoretical model, the expected loss imposed by accidental fire, i.e., the damage caused by such externality, is measured by the effective rent yielded by the parcels within the reach of accidental fires. The effective land rent yielded by a parcel, for its turn, is proxied by the parcel's land area allocated to crops, pasture or silviculture (to be referred as "CPS" area), the main income-generating activities of rural properties of the study region (IBGE: 2010). Income from timber and non-timber forest products is ignored owing to the lack of information needed to distinguish productive (under exploitation) forestland from non-productive (untouched/fully degraded/unproductive) forestland. Synthetically:

1. The value of agents-own effective rent under risk of being lost owing to fires him/she eventually starts in a given parcel is thus given by the total CPS area that (1.i) belongs to agent's property and (1.ii) belongs to the neighborhood of the parcel in question; this is denoted by A_i.
2. The value of second party (neighbor farmers') effective rent set under risk by fires the agent eventually starts in a given parcel is given by the total CPS area that (2.i) belongs to other agents' properties and (2.ii) belongs to the neighborhood of the parcel in question; this is denoted by A^*_i.

The term e_{2i} accounts for non-observable factors that affect the expected own-rent loss, such as the probability of fire going out of control what tends to vary across parcels, owing to microclimate and biophysical features (Mattos & Uhl: 1994, p. 155, Almeida & Uhl: 1995, p.1756, Sorrensen: 2000, 2004 and 2009, Cardoso et al: 2003, Simmons et al: 2004, Nepstad et al: 2001).The term e_{3i} it is also a random shock which comprises, for instance, the bargaining power of the agent that owns parcel "i".

It is necessary to highlight that no metric for the cost of preventive measures (term "μ_x" in the theoretical model) is available on the data employed (see section 3.5 below). Such component of the private net benefit of fire use is left for the error term, what is one of the main limitations of the empirical analysis[58].

After the parametrization, the pay-off of fire-based land conversion becomes:

$$PNB^e_i = \beta_0 + \beta_1 LC_i + \beta_2 A_i + \beta_3 A^*_i + \varepsilon_i \quad (5)$$

Where $\beta_0 = \alpha_1 + \alpha_2 + \alpha_3$ and $\varepsilon_i = e_{1i} + e_{2i} + e_{3i}$. Subsuming the covariates to the 1 x 4 vector "z" and the coefficients to the 4 x 1 vector "β", the equation takes the synthetic form $PNB^e_i = z\beta + \varepsilon_i$. The probability of fire being used in parcel "i", denoted as $P(y=1|z)$, is equivalent to $P(PNB^e_i > 0|z) = P(\varepsilon_i > -z\beta|z) = \Phi(z\beta)$, with $\Phi(.)$ representing the cumulative gaussian distribution function. Therefore, the econometric model to be estimated at parcel level is a discrete choice model (Wooldrigde: 2002, cap. 15; Cameron & Trivedi: 2008, cap.14) where the dependent variable is the probability of a parcel to be treated with fire.

3.4.2 Sources of endogeneity

Assuming, for the sake of the argument, that, for each parcel, there are always two neighboring parcels, one belonging to the same agent and other belonging to other agent, the structural form of the econometric model can be written as[59]:

$$y_i = \beta_0 + \beta_1 A_j + \beta_2 A^*_k + \beta_3 U_i + b_i + u_i \quad (6)$$

$$A_j = \gamma_0 + \gamma_1 y_i + \gamma_2 y^*_m + \gamma_3 V_j + c_j + v_j \quad (7)$$

$$A_k = \delta_0 + \delta_1 y_n + \delta_2 y^*_i + \delta_3 V_k + c_k + v_k \quad (8)$$

Where $y_.$ is a dummy which takes unitary value when the parcel is treated with fire, A. is the parcel area allocated to CPS, U. and V. are (potentially distinct) vectors of control variables and b. and c. are vectors of non-observables. Random shocks are represented by u. and v.

Subscripts discriminate parcels. The star highlights parcels that belong to other farms than the one whose parcel is being explained in the equations[60].

Equation (6) captures fire use decision of a farmer and equations (7) and (8) capture, respectively, land use decision of the same farmer and land use decision of one of his/her neighbors.

The structural representation clarifies the two potential sources of endogeneity regarding neighboring parcels' areas allocated to CPS, i.e., A_j and A_k: (i) they are potentially determined by the decision to treat the parcel "i" with fire, a case of simultaneity bias (equations 7 and 8)

[58] What is clearly suggested by the paper of Bowman et al (2008).

[59] This presentation follows Moffit (2001) and Robalino & Pfaff (2011).

[60] Thus i and j belong to the same farm and k and n to other farm.

and; (ii) they can be related to non-observables (b and c can contain common variables) that influence both fire use and land use decisions, a case of omitted variable bias.

Focusing on neighboring parcels that belong to other agents (equation 8), the intuition behind the first potential source of endogeneity lies on the conception that agents manage their land in order to maximize expected profits (land rent) in an environment where accidental fires coming from neighboring farms are probable but uncertain[61]. They might do it through allocating activities with lower sensitivity to fire and/or with lower profitability to parcels that are closer to the parcels of neighboring farms where fire has being used more recurrently up to the present day.

Neighboring parcels can also belong to the same agent (equation 7). In this case, simultaneity comes from the fact that it is the same agent that decides whether to burn or not a given parcel and how neighboring parcels will be allocated for alternative land uses. Maximization of the whole farm expected profit requires the two decisions to be made together.

The second source of endogeneity, omitted nonobservables, is induced by factors that exert common influence over land use and fire use. The provision of rural extension (or technical assistance) services by governmental agencies is one of such factors (Schuck et al: 2002). It tends to be (a) positively correlated with the productivity achieved on specific activities, and, thus, with profit differentials of alternative land uses and; (b) negatively correlated with the propensity of using fire (Schuck et al: 2002)[62]. Local market conditions, output and input prices, specially, also influence both land use decision and technological decision (Arima et al: 2007).

3.4.3 Spatial autocorrelation

Spatial autocorrelation can affect the dependent variable, making coefficient estimates biased and inconsistent, and also the error term, what leads to inefficient estimation (Anselin & Bera: 1998, section II). Such undesirable outcome is possible even after the channels, discussed in the last subsection, through which endogeneity manifest, are (partially) "closed" by instrumental variables (Kelejian & Prucha: 2010).

[61] They face a problem very close to the one of optimal investment in wildfire-protection as studied by Shafran (2008). The principle stated by the author that "(…) the risk one homeowner faces depends on the risk mitigation decisions of neighboring homeowners." clearly applies to the problem under examination, when "homeowners" are replaced by "farmers".

[62] As seen on field, public rural extension agencies are the main sources of diffusion of fire-free land management techniques.

AFU tend to cluster in Paragominas' landscape, as evidenced by the significance test for the Moran's I (Anselin & Bera: 1998, section IV) calculated for the binary variable indicating whether land parcels were treated with fire during 2010 (the dependent variable)[63]. Thus, there is reason for worrying about spatial autocorrelation in the dependent variable.

Unobserved socioeconomic factors such as rural extension provision and market conditions, that are pertinent predictors of both fire use and land use, as already mentioned, can also exhibit a clustered pattern in space, making the residuals spatially autocorrelated. For instance, where prices of annual crops such as rice, beans and cassava and also prices of inputs such as fertilizers are higher, slash and burn agriculture tends to be a relevant land use (Denich et al: 2005, Kato et al: 1999, Arima et al: 2007). This agricultural system, on Brazilian Amazon, comprises (i) recurrent AFU and (ii) cultivation of small parcels of land no larger than three hectares per year (Denich et al: 2005, Börner et al: 2007). What gives place to a land use pattern where fire coexists side by side with small CPS areas[64].

3.4.4 Identification strategy and estimation methods

For addressing the two varieties of biases caused by endogeneity, the instrumental variable (IV) approach conceived by Robalino & Pfaff (2011) is followed. It can be argued that the slope of neighboring parcels, being them owned by the same agent or not, is a consistent IV. First it is correlated with land use decision, as claimed by Robalino & Pfaff (2011) and observed in practice in Paragominas municipality, where the price of land, a reflection of its rent generating potential, is negatively correlated with slope (Parry: 2012, Gardner: 2012[65]). Second, being it a topographic characteristic, it cannot be affected by human decisions, what rules out the simultaneity bias and, at least partially, the omitted variable bias.

The biases imposed by rural extension services provision and local market conditions cannot be completely eliminated. But they can be attenuated by the fact that the offer of rural extension services and as well as input and output prices tend to be correlated with remoteness (Waichman et al: 2007, p.582, Chomitz & Gray: 1996, p. 491), as measured by distance from roads. Adding this factor to the model as a control variable is a way to reduce the bias (a strategy also employed by Robalino & Pfaff: 2011).

[63] The hypothesis of no spatial autocorrelation is rejected for a significance level above 0.999 (p-value below 0.0001). The test was performed for two neighborhood definitions, 2km and 5km.

[64] Thus, the ommitted nonobservable "slash-and-burn cluster" explains both fire use as the size of CPS areas.

[65] Models estimated by Pfaff et al (2007), at census tract scale, reveal a negative and significant influence of steep slopes over deforestation for Brazilian Amazon from 1976 to 1987.

Maximum likelihood (MLIV) and the less efficient two stage minimum chi-square (Newey: 1987), with bootstrapped residuals (IV2S), are the estimation methods chosen (Cameron & Trivedi: 2008, p.467). STATA ® built-in routines are available for both on the command "ivprobit".Ordinary (i.e., non-IV) probits are also estimated.

The general form of the model is:

$$P(y_i=1|z) = \Phi(\beta_0 + \beta_1 LCi + \beta_2 Ai + \beta_3 A^*i + \beta_4 d_i) \ (9)$$

Where $P(y_i=1|z)$ is the probability of parcel "i" to be treated with fire, z is the vector of covariates and d the distance to the nearest road.

By taking as the dependent variable not the probability of fire use but the binary variable indicating fire use, it is possible to estimate a (linear) model that addresses the two sources of spatial autocorrelation and also simultaneity and omitted variable bias (related with the fire-use-land-use nexus). This is what the SARARIV model can do, by combining the spatial autoregressive with autoregressive disturbances specification (SARAR, Kelejian & Prucha: 2010) with the instrumental variable approach (Drukker et al: 2011).

Such model is also estimated with the help of STATA 12 ® routines, through a procedure that combines two-stage instrumental variables estimation with the generalized method of moments (GMM; see section 6.1 of Drukker et al: 2011 for the details). The model consists in the two equations below, the first one capturing the causal relation of interest and the second one the possibility of spatial autocorrelation in the residuals.

$$y = \theta_0 + \theta_1 LC + \theta_2 A + \theta_3 A^* + \theta_4 d + \lambda wy + \xi \ (10.a)$$

$$\xi = \rho w\xi + \varepsilon \ (10.b)$$

Where the dependent variables and the covariates are written as N x 1 vectors, N being the total number of parcels. The spatial weight matrix, w, N x N, has in its i-th row and j-th column a number equal to the reciprocal of the Euclidian distance between parcels "i" and "j". A threshold distance of 10 km is considered. The elements of the matrix w that refer to parcels more than 10 km away from each other are assigned with zero.

Coefficients λ and ρ measure, respectively, the degree of spatial autocorrelation for the dependent variable (clustering) and for the residuals. If both are statistically significant, the other (non-spatial) econometric models estimated provide coefficients that are biased, inconsistent and inefficient.

3.4.5 Sample design

Only parcels whose neighborhood contains parcels belonging to other agents are considered, given the paper's goal of looking for evidences that neighbors' land uses matter for agent's decision on where to use fire. This question does not arise for parcels geographically isolated from the effects of other farmers' decisions, what make them not useful for the analysis envisioned.

Nevertheless, the lack of objectiveness of the concept of "geographical isolation" can distort estimation results. In order to mitigate this, estimation is done, separately, on ten subsamples, each one taking a specific distance threshold as the reference for the definition of parcels' neighborhood. More precisely, in each subsample the extension of parcels' neighborhoods takes a particular integer value from 1 to 10 km.

Only parcels belonging to farms where fire was used during 2010, the period for which data is available, are considered. This is the second and last criterion adopted for selecting observations for estimation. The rationale lays, again, on the analysis goal, which is not to explain whether a farmer would choose fire or not, among the available techniques of land conversion, but where a famer would choose to use fire. The model built on section 3.3 is a locational model for AFU and not a full model explaining why fire is the technique selected by a rational farmer under the restrictions he/she faces.

Incorporating to estimation farms where fire use was not detected on the period of observation, factors that are not controlled for, such as human and financial capital hold by farmers, can distort results. For instance, AFU is less probable for farmers that are richer and whose technical knowledge is higher (Barlow et al: 2012), being the CPS areas of their neighbors large or small. The unobservable and thus uncontrolled variation of wealth and technical knowledge among parcel owners can, in this example, be taken as an evidence of the lack of power of the neighborhood effect going from CPS areas of agent "b" to the choice of agent "a" to treat or not his/her parcels with fire.

To discard farms where no evidence of AFU was detected is a measure aimed at making the estimation sample more homogenous for uncontrolled factors that drive the decision on land conversion techniques[66].

[66] This is a rough way to eliminate confounders, i.e., mechanisms whose empirical efectiveness is a question beyond the scope of the paper but that can, nevertheless, bias the identification of the causal relation under investigation.

3.5 Data

Data for all model variables is originally available at finer spatial scales (observational levels) than the one for which the model is applied, the parcel scale (section 3.4). Land use, for instance, is available in a grid of 30 x 30 m. ArcGIS 10 ® tools are employed to generate measures at parcel level. This section aims to describe how this is done.

3.5.1 Spatial units

The database of the Rural Environmental Registry ("RER" or "CAR", in Portuguese) contains information that corresponded, in April 2012, to 83% of the municipality's rural property area (SIMLAM: 2012, Neidemeier: 2011; map 2).

It was necessary to keep one of the properties out of the estimation sample owing to ambiguity regarding the ownership of the whole land area. Even being assigned by RER to forest stewardship firm, whose management practices are publicly known to be certified by international agencies (the Forest Stewardship Council, FSC), fire and agriculture could be detected within the property boundaries, casting a doubt whether the land use decisions are solely being made by the company. After discarding this property, 827 farms are left. But, for econometric estimation, it is considered only the farms for which at least one parcel meets the sample selection criteria adopted (section 3.4.5 above), a total of 136 farms out of 827.

To define parcels, the property polygons were partially subdivided by overlapping the map with their boundaries with a grid of 1km x 1km. The huge size of properties guarantees that the subdivision works, i.e., that fragments smaller than the whole are obtained for all properties. This is attested by table 3.1 which brings statistics for total farm area and number of parcels for the 136 farms considered for econometric estimation[67].

The final set of spatial units - the observational units of the empirical exercise - is composed of polygonal fragments of diverse shape and size with only the largest ones (interior polygons, see section 3.4.1), whose areas is of 1km^2 (or 100 hectares), having a squared shape form.

Table 3.1 Statistics for total farm area and number of parcels (farm level)

Stat	N	N(area < 1km)[a]	mean	median	sd	max	min
Farm area (km)	136	5	28.70	18.57	33.01	225.38	0.55
Number of parcels	136	DA[b]	42.84	30.50	40.91	267	4

[67] Even farms with an area smaller than 1km are subdivided since the irregular (non-squared shape) format of their boundaries and their position in space do not perfectly match the format and position of the squared shaped cells of the grid (that's why the minimum number of parcel per farm is not 1 but 4).

[a]number of farms with total area below 1km, [b]does not apply.

Source: georreferenced database.

Parcels with less than one hectare of size are discarded for being below the resolution of land use and slope data (next subsections), which is of 100m x 100m, i.e., exactly one hectare.

As panel 1 shows, restrictions imposed by the criterion of selecting parcels which are in proximity of other agents' parcels is relaxed for the subsamples where neighborhoods cover radius of more than 6 km. Beyond that threshold, all parcels belonging to farms where fire was used during 2010 are considered for estimation.

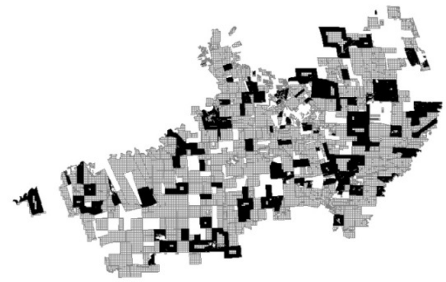
In order to have all the information needed to measure neighborhood effects, all cells within a distance of 10km from Paragominas municipality boundaries are part of the database (figure 10). What also allows for overcoming the fact that RER polygons do not cover the whole land area within municipality's boundaries. The "holes" remaining are not necessarily areas without private owners (or without untitled holders), but mostly properties which have not been included in the RER until June 2012 (the reference date for the data).

Figure 10 Parcels of the 5km neighborhood sample (black) and cells required for computing variables for the neighborhoods (grey)

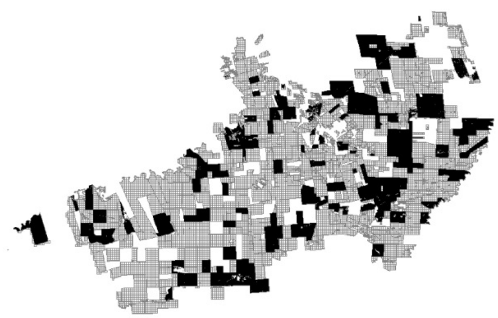
Panel 1 Parcels in the subsamples for some neighborhood definitions (black)

1km (3420 parcels)

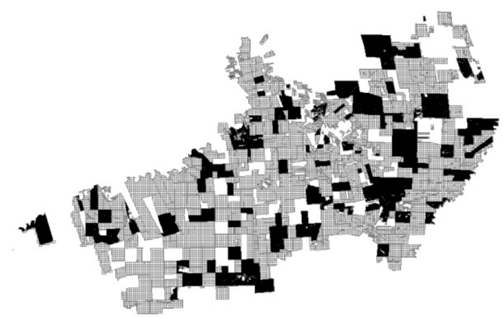
3 km (5432 parcels)



5km (5645 parcels)



8 km (5656 parcels)



10 km (5656 parcels)

3.5.2 Neighborhoods

All parcels whose centroid falls within a pre-defined radius of reach are considered to be exposed to the risk of being harmed by accidental fires started in a given parcel. The neighborhoods of the parcels are therefore defined in terms of a distance threshold. To know which value (or values) should be considered for this threshold, the literature on fire propagation in Brazilian Amazon landscapes is briefly examined.

Mendonça et al (2004) reports, from survey data collected during 1994 and 1995, Landsat images and flyovers made in 1998, that, considering the years of 1995 and 1998, the greatest distance through which fire had spread within an area of primary forest was 4 km. Similarly, on the field and satellite data corresponding to two sites located in the state of Pará and one in the state of Mato Grosso (both on Brazilian Amazon), evaluated by Alencar et al (2005, p.11), most (91%) of 1998 episodes where a fire set for agricultural purposes penetrated into the forest up to 4 km[68].

Owing to the fact that primary forest areas are generally more humid and, thus, less susceptible to fire, compared to deforested areas dominated by agriculture (Mattos & Uhl: 1994, p. 155, Simmons et al: 2004, p.84), the radius of reach of accidental fire spread can be conjectured to be larger on the second type of landscape (Sorrensen et al: 2000, Nepstad et al: 2001). This can perhaps explain why Alencar et al (2005, p.11) found evidences of fire spreading beyond 10 km only for the study area where the savannah vegetation is present (the other evidences mentioned refer to forestland).

It was possible to find only one study that estimates the reach of accidental fires on this type of landscape. Nepstad et al (1999a) have collected data on fire use and accidental fires through a survey conducted on 1996 in five regions of Brazilian Amazon (states of Pará, Mato Grosso, Rondônia and Acre). The declared reach of accidental fires across farm areas allocated for pasture varied from 2 to 901 hectares, depending on total area allocated for such land use (Nepstad et al: 1999a, table 3.11). To cover a circumference with 900 ha of area, fire must cross a radius of 1.7 km[69]. But the values refer to the distance crossed by fire within the farm of the observer. Contiguous farms could also be affected. To damage 900 ha of pasture of each of four neighboring farms (a total area of 3,600 ha), fire must cross a radius of 3.38 km.

[68] It is necessary to add that 1998 was a peculiar year characterized by a severe drought that took Brazilian Amazon, caused by the El Nino Southern Oscillation (ENSO) (Alencar et al: 2011).

[69] The estimations consider the area of a circumference to be of $\pi r^2 \approx 3.14\ r^2$, where r is the radius.

The evidences discussed do not point to a precise threshold for the radius of spread of accidental fires on landscapes of Brazilian Amazon. To address this imprecision, ten lengths of radius, from 1km to 10 km (including both thresholds) are tested. Each one can be conceived as a peculiar definition of neighborhood. The econometric models are separately estimated for each of these ten possibilities.

Within the radius of reach of accidental fires there are, generally, parcels owned by the agent that plays the role of fire starter but also parcels that belong to other agents which play the role of passive victims. Once the information on rural property boundaries is available, a straightforward criterion can be used to match parcels and agents: identify the agent that owns the property into which the parcel is located.

Hereafter, for a given generic parcel, the elements of the set formed by its neighboring "own-parcels" and the elements of the set formed by its neighboring "second-party parcels" will be indicated, respectively, by subscripts "v" and "w".

The function "dnearneigh" of the "spdep[70]" package for the open-source software R[71] was used to create a list matching every parcel to its neighboring parcels within a distance of up to 10km. This list was enriched with information on (a) the number of the property to which each parcel belong and; (b) the distance between every pair of neighboring parcels.

3.5.3 Land use and fire use data

The most detailed and updated land use map available for Brazilian Amazon, TerraClass 2010, was elaborated from satellite imagery by the National Institute for Space Research (INPE)[72]. Description of the classes and methodology are referred to TerraClass (2011 and 2013). Categories were aggregated when capturing roughly the same land use, and excluded from analysis when they correspond to land uses that (a) could not be observed/ identified; (b) cannot be converted to primary activities (such as urban areas, water, mining sites, etc.), being, thus, not eligible for studying the choice of land management technique. The first and the third columns of table 3.2 describe how categories were redefined.

Portions of the land parcels classified under excluded categories are left out of the analysis. For every parcel, the values of all model variables (including the dependent variable) where calculated after discarding the mentioned portions.

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[70] http://cran.r-project.org/web/packages/spdep/spdep.pdf
[71] http://www.r-project.org/
[72] Available online at http://www.inpe.br/cra/projetos_pesquisas/terraclass2010.php

Land areas that gone through all the year of 2010 covered with primary forests cannot have given place to intentional AFU but only to accidental fire spreads. It is, therefore, necessary to discard fire detections that fall on primary forest. The second column of table 3.2 indicates as "possible" the land uses where the decision on the land management technique (fire against fire-free alternatives) could have taken place during 2010.

Table 3.2 Classification of land use and of the possibility of agricultural fire use (AFU)

<table>
<tr><th>Original Classes</th><th>AFU</th><th>Aggregated classes of land use</th></tr>
<tr><td>Crops</td><td>Possible</td><td>Crops</td></tr>
<tr><td>Abandoned pasture</td><td>Possible</td><td rowspan="4">Pasture</td></tr>
<tr><td>Pasture (clean and on good soil condition)</td><td>Possible</td></tr>
<tr><td>Pasture on degraded soil</td><td>Possible</td></tr>
<tr><td>Pasture with grass</td><td>Possible</td></tr>
<tr><td>Silviculture</td><td>Possible</td><td>Silviculture</td></tr>
<tr><td>Primary forest</td><td>Not possible</td><td rowspan="4">Forest</td></tr>
<tr><td>Primary forest under clouds</td><td>Not possible</td></tr>
<tr><td>Secondary vegetation grown from 2008 to 2010</td><td>Possible</td></tr>
<tr><td>Secondary vegetation not grown from 2008 to 2010</td><td>Possible</td></tr>
<tr><td>Deforestation during 2010</td><td>Possible</td><td rowspan="2">Not considered as land cover category</td></tr>
<tr><td>Area burned during 2010</td><td>Possible</td></tr>
<tr><td>Non observed (covered by clouds)</td><td>Not possible</td><td rowspan="2">Excluded (a)</td></tr>
<tr><td>Non-identified</td><td>Not possible</td></tr>
<tr><td>Mining área</td><td>Not possible</td><td rowspan="6">Excluded (b)</td></tr>
<tr><td>Other natural landscape (sandbanks, mountains, etc.)</td><td>Not possible</td></tr>
<tr><td>Mining área</td><td>Not possible</td></tr>
<tr><td>Other natural landscape</td><td>Not possible</td></tr>
<tr><td>Urban área</td><td>Not possible</td></tr>
<tr><td>Water</td><td>Not possible</td></tr>
</table>

Source: INPE (2011) and author's own reclassification.

The monitoring of the fire activity is conducted, by INPE, from "hotpixel" data, i.e., georeferrenced 1km x 1km pixels representing the approximate place where fire was detected from NASA's MODIS sensor (http://modis.gsfc.nasa.gov/). Only fires with at least 30 m length and at least 1 m width are captured by satellite sensors (INPE: 2013, Arima et al: 2007)[73].

[73] The probability of capturing fire started from non-anthropogenic sources (such as lightning strikes) is ignorable. As Fearnside (1990) puts it, "[r]easons for believing that the principal cause of pre-Columbian forest

In this paper, hotpixel data were collected directly from MODIS Active Fire & Burned Area Products website (http://modis-fire.umd.edu/index.html) strictly for the year of 2010, in order to match the period of the land use map. Two satellites, Aqua and Terra are considered, being their hotpixel counts summed up for each parcel.

The dependent variable is a dummy which assumes unitary value for parcels (a) intercepted by the centroid of a hotpixel and (b) whose precise location of the interception was not, during 2010, (b.1) taken by land uses excluded from analysis (table 3.2) or (b.2) allocated to primary forest. Contrariwise, the dummy is assigned with zero.

3.5.4 Slope

Slope have a non-ignorable variation along Paragominas[74] and specifically, along our spatial units. It is a factor that matters concretely not only for defining the price for which land is transacted but also (what goes in the same direction) as a determinant of agricultural profitability (Parry: 2012, Gardner: 2012).

From the 30 m resolution Digital Elevation Model (DEM), a grid with 100 m x 100 m cells was built, each one holding a particular value for percent slope[75]. A parcel is generally intercepted by more than one cell of the slope grid, i.e., slope varies within parcels. To calculate the average slope of the parcel, each fragment of the intersection between the slope grid and parcel polygons is weighted by its area, as the formula below shows:

$$\bar{s}_v = \frac{\sum_{j=1}^{J_v} s_{vj} a_{vj}}{\sum_{j=1}^{J_v} a_{vj}}$$

Where s_{vj} is the value of slope in the j-th fragment into which the v-th parcel was subdivided by the intersection, a_{vj} is the area of the j-th fragment and J_v is the total number of fragments corresponding to parcel v. In the same fashion, the average for the squared slope is given by:

$$\bar{ss}_v = \frac{\sum_{j=1}^{J_v} {s_{vj}}^2 a_{vj}}{\sum_{j=1}^{J_v} a_{vj}}$$

burning was human, however, include the very limited extent of lightning-caused fires in Amazonia today. Usually only a single tree or a very small patch is burned when lightning strikes". Aragão & Shimabukuro (2010, p.329), argue, in the same direction that "(…) fire is naturally rare in Amazonia, and its occurrence is strongly associated with human ignition for land management." Further confirmation is given by the excerpts that follow. "Live mature [Amazonian] forest (…) is considered to be minimally vulnerable to fire because high rainfall coupled with closed canopy settings creates moist microclimatic conditions in the understory and combustion is difficult (Sorrensen: 2000)". "(…) Almost all fire in tropical forests is caused by people (…) (Carmenta et al: 2011)."

[74] Percent slope varies, within the municipality borders, in the range of 0 to 46% and the coefficient of dispersion (standard deviation / mean) is of 94%.

[75] For this, the function "Surface" of ArcGIS © Spatial Analyst Toolbox was used. Resolution was reduced to save processing time.

From these two statistics, calculated at the parcel level, the average and the standard deviation of the slope on the neighborhood of a generic parcel can be obtained from the formulas bellow:

$$\bar{s}_i = \frac{\sum_{v=1}^{V_i}\sum_{j=1}^{J_v} s_{vj} a_{vj}}{\sum_{v=1}^{V_i}\sum_{j=1}^{J_v} a_{vj}} = \sum_{v=1}^{V_i} \bar{s}_v \left(\frac{\sum_{j=1}^{J_v} a_{vj}}{\sum_{i=1}^{V_i}\sum_{j=1}^{J_v} a_{vj}}\right)$$

$$\sigma_i = \frac{\sum_{v=1}^{V_i}\sum_{j=1}^{J_v} (s_{vj} - \bar{s}_i)^2 a_{vj}}{\sum_{i=1}^{V_i}\sum_{v=1}^{J_v} a_{vj}} = \sum_{v=1}^{V_i} \bar{s}\bar{s}_v \left(\frac{\sum_{j=1}^{J_v} a_{vj}}{\sum_{v=1}^{V_i}\sum_{j=1}^{J_v} a_{ij}}\right) - \bar{s}_i^{\,2}$$

Where V_i is the number of neighboring own-parcels for parcel i. The calculus for neighboring second-party parcels is equivalent.

3.5.5 Model variables and subsamples

Besides the variables already discussed, it is additionally included the Euclidian distance from the nearest roads indicated by the shape file of the Ministry of transport (MT: 2013), what partially mitigates omitted variable biases (see section 3.4).

Table 3.3 lists model variables and the statistical summary of variables for selected subsamples is found on tables 3.4-3.6.

3.5.6 Robustness test

Hotpixels consist on centroids of square-shaped 1km x 1km cells, what means that, when located within a distance of less than 1km of a farm boundary it is impossible to know which farm have started the fire observed. In order to assess how conclusions can be affected by the imprecision of the dependent variable, a simulation is performed.

Around each of the hotpixels that did not fell on land uses non-convertible to agriculture or into forests (see section 3.5.3) a (circular) buffer of 1km was created in order to identify the parcels where the fire could have been detected. With a random number generator, all parcels within 1km of a given hotpixel are assigned with a probability (a number in the [0;1] range) of have given place to the generation of the fire detected. The parcel with largest value is chosen as the potential source of fire.

This exercise of randomly assigning hotpixels to proximate parcels can be replicated as desired in order to generate a set of vectors for the dependent variable. By running the models on such set of vectors it is possible to know whether results are robust to the imprecision of the hotpixel data. This is done from a set of 100 alternative vectors, each one of them regressed against the explanatory variables with the SARARIV model. The values of the Student’s t-statistic for the coefficients of own CPS area and second-party CPS area, estimated for each replication, can be compared with the ones yielded by estimation from the observed dependent variable vector.

Table 3.3 Variables of the model

N	Variable	Class	Notation	Measure for?	Unit
0	Fire use dummy	Dependent	d_fu	DA	-
1	Total own CPS area in the neighborhood	Effect to be measured	w_cps_own	Cost of accidental fires	ha
2	Total second-party CPS area in the neighborhood	Effect to be measured	w_cps_2nd	Cost of accidental fires (compensation)	ha
3	Crop area of the parcel	Controls	Crop	Technical economy of fire	ha
4	Pasture area of the parcel		Past	Technical economy of fire	ha
5	Silviculture area of the parcel		Silv	Technical economy of fire	ha
6	Forest area of the parcel		Fore	Technical economy of fire	ha
7	Distance from roads		d_roads	Transport costs	km
8	Average slope in the neighboring parcels, own parcels only	IV	w_slope_av_own	Instrumental variable	%
9	Average slope in the neighboring parcels, second party parcels only	IV	w_slope_av_2nd	Instrumental variable	%
10	Standard deviation of slope in the neighboring parcels, own parcels only	IV	w_slope_sd_own	Instrumental variable	%
11	Standard deviation of slope in the neighboring parcels, second-party parcels only	IV	w_slope_sd_2nd	Instrumental variable	%

Source: sections 3.4 and 3.5.

Table 3.4 Summary of variables for the 1km neighborhood subsample

Variable	N	Mean	Standard deviation	Minimun	Maximum
d_fu	3420	0.06	0.23	0	1
w_cps_own	3420	53.21	59.91	0	294.84
w_cps_2nd	3420	24.54	39.42	0	251.37
crop	3420	3.71	13.46	0	99.99
past	3420	14.88	23.50	0	99.75
silv	3420	0.10	1.58	0	42.87
fore	3420	31.07	30.46	0	100.00
d_roads	3420	10.55	8.64	0	40.08
w_slope_av_own	3420	4.28	2.27	1.07	15.53
w_slope_av_2nd	3420	4.49	2.82	0.66	24.35
w_slope_sd_own	3420	1.02	1.04	0	6.88
w_slope_sd_2nd	3420	0.58	0.88	0	9.86

Source: Georreferenced data referred on section 3.5

Table 3.5 Summary of variables for the 5km neighborhood subsample

Variable	N	Mean	Standard deviation	Minimun	Maximum
d_fu	5645	0.07	0.25	0	1
w_cps_own	5645	784.16	640.73	0	3310.98
w_cps_2nd	5645	1466.86	1063.77	0	5619.48
crop	5645	5.68	18.33	0	100.00
past	5645	18.52	28.65	0	100.00
silv	5645	0.34	4.43	0	100.00
fore	5645	43.81	37.75	0	100.00
d_roads	5645	10.90	8.68	0	40.08
w_slope_av_own	5645	4.27	1.47	1.21	11.80
w_slope_av_2nd	5645	4.33	1.31	1.93	13.29
w_slope_sd_own	5645	1.98	1.13	0.09	6.06
w_slope_sd_2nd	5645	2.09	1.07	0	5.59

Source: Georreferenced data referred on section 3.5

Table 3.6 Summary of variables for the 10km neighborhood subsample

Variable	N	Mean	Standard deviation	Minimun	Maximum
d_fu	5656	0.07	0.25	0	1
w_cps_own	5656	1322.93	1037.24	0	4192.74
w_cps_2nd	5656	7738.73	3778.39	6.38	19107.83
crop	5656	5.67	18.31	0	100.00
past	5656	18.49	28.64	0	100.00
silv	5656	0.38	4.77	0	100.00
fore	5656	43.88	37.78	0	100.00
d_roads	5656	10.93	8.70	0	40.08
w_slope_av_own	5656	4.26	1.35	1.21	11.80
w_slope_av_2nd	5656	4.38	1.00	2.39	8.04
w_slope_sd_own	5656	2.06	1.14	0.09	6.06
w_slope_sd_2nd	5656	2.31	0.98	0.78	4.65

Source: Georreferenced data referred on section 3.5

3.6 Results and discussion

Table 3.7 Selected results*

NB [a]	Overidentification test (p-values) [b]	Wald test (p-values) [c]	w_cps_own [d]			w_cps_2nd [d]		
			MLIV [e]	IV2S [e]	SARARIV [f]	MLIV [e]	IV2S [e]	SARARIV [f]
2	gmm: 0.72; 2sls:0.77	2S: 0.94; ML: DA	DA	ns	*** -	DA	ns	* +
3	gmm: 0.79; 2sls:0.81	2S: 0.17; ML: < 1%	*** -	** -	*** -	Ns	ns	Ns
5	gmm: 0.98; 2sls: 0.99	2S: 0.08; ML: DA	DA	*** -	*** -	DA	ns	Ns
6	gmm: 0.85; 2sls: 0.88	2S: 0.19 ; ML: 0.09	*** -	*** -	*** -	Ns	ns	Ns

Source: georreferenced database.

* Detailed results on appendix A.3.1.

[a] Neighborhoods defined in terms of the radius of reach of accidental fires, in kilometers.

[b] Tests made with ordinary least squares instrumental variables regressions (STATA ® “ivregress” command). For GMM, the p-value of Hansen’s J test is reported and for two stage least squares (2SLS), the p-value of Sargan (score) test is reported.

[c] Results for Newey’s two-step estimator, indicated as “2S” (coefficients and Wald test) were obtained through bootstrapping the residuals. “ML” indicates the p-values obtained from maximum likelihood (instrumental variable) estimation.

[d] MLIV = maximum likelihood instrumental variable probit and IV2S = two stage minimum chi-square instrumental variable probit with bootstrapped residuals. The number of stars (*) indicate the significance level of coefficients (p): * p<0,05, ** p<0,01, *** p<0,001. The signal after the stars is the signal of the coefficient (when significant). “ns” stands for non-significant and DA for does not apply. This last possibility indicates that the optimization routine for the maximum likelihood IV (MLIV) estimator does not converge.

[e] The results for (non-IV) probit and IVML probit are robust for heterocedasticity.

[f] IV model with spatial lagged dependent variable and spatial error.

Considering as parcels’ neighborhoods the parcels within 1km, only the fraction of the CPS area in the neighborhood self-owned seems to matter. This evidence has to be taken with care, because it is driven, most of all, by the exiguity of the neighborhood considered: 1km is exactly the size of the grids cells from which the parcels are defined, what makes second party CPS area perhaps too small to be a significant predictor fire-use location.

Estimations made for broader neighborhood definitions do not lead to the refutation of the hypothesis that second party CPS area is irrelevant. All three instrumental variable models result into coefficients statistically equivalent to zero, for all the ten neighborhood definitions. Contrariwise, agents’-own CPS area exerts significant and negative influence over the probability of treating a parcel with fire, for all neighborhood definitions and for almost all models - the coefficient estimated through SARARIV is negative and significant for all neighborhood definitions. Therefore farmers, when starting a fire, do care for the risk of accidentally burning crops, pasture and forest plantations, but only when such assets belong to them.

In fact, for all the neighborhood definitions for which the MLIV could be estimated[76], the impact, over the probability of treating a parcel with fire, of a 1% increase in the neighboring CPS area owned by farmers is at least three times larger than the impact of a 1% increase in the neighboring CPS area belonging to others, as shown in table 3.8. What is corroborated by the ratio of the coefficients for own-CPS area and 2nd-party CPS area, weighted by the average value of the corresponding covariate[77], calculated from SARARIV estimates (last column of table 3.8). This last indicator is larger than the unity for all neighborhood definitions considered. Conclusively, agents care more about their assets than the assets that belong to others, when deciding to take or not to take a course of action that can harm any assets within a given radius, no matter who own them.

The robustness test corroborates the findings. None of the 100 replications yielded a negative and significant coefficient for second-party CPS area. But, for the coefficient of agent's-own neighboring CPS area, the proportion of replications where a negative and significant result was achieved is not zero, for any of the neighborhood definitions considered (see the tables of appendix A.3.2). Panel 2 presents selected results of the simulations for neighborhoods encompassing radii of 2 and 5 km (detailed results on appendix A.3.2).

If estimation was pursued without addressing the endogeneity of second parties' CPS area, this variable would appear to be a significant source of influence, owning mainly to inconsistency. A wrong conclusion avoided by the identification strategy.

The use of a model that also addresses spatial autocorrelation on the dependent variable and on the error term proves to be necessary. It is verified that both sources of spatial dependence operate on the data (the estimates of λ and ρ are significant for all neighborhood definitions, table 3.9).

The two instruments (average slope and standard deviation of slope) are strong for all neighborhood definitions, as revealed by table 3.10. The overidentification test does not reject the null hypothesis for any neighborhood definition what evidences the adequacy of the identification strategy for the data studied.

[76] I.e.,the ones for which the optimization algorithm converges.

[77] This indicator is a coherent measure for the ratio of the average impact of own-CPS area and the average impact of 2nd party CPS area. This is guaranteed by the fact that SARARIV is a linear model, since the dependent variable is binary and not a probability, therefore the coefficients capture the marginal effect of the covariates.

Regarding land uses, the larger the parcel area allocated to crops, the greater the likelihood of fire use in the parcel, for all subsamples examined. The same being true for pasture. Forest plantations and natural forest areas have no clear effect. It is, therefore, confirmed that crops and pasture are the land uses mainly related with AFU on the post-greening Paragominas.

Distance to roads exert a significant and negative effect on the probability of a parcel being treated with fire (as observed by Sorrensen: 2004, p. 410, Simmons et al: 2004, p.91, discussed by Bowman et al: 2008, p.128 and simulated by Arima et al: 2007, p. 561) only for subsamples with parcels' neighborhoods extending from 3 km to 4 km. Colinearity with the land use variables such as neighboring CPS area, which are determined, for their turn, by spatial explicit factors, as the majority of land use statistical models demonstrate (Nelson & Geoghegan: 2002, Chomitz & Gray: 1996; chapter 3 of this thesis) explains why the effect is non-significant for neighborhoods encompassing more than 4 km. It is beyond this threshold that the colinearity become stronger enough to make the individual effect of roads non detectable.

Table 3.8 Elasticity of own and 2nd party CPS area

Neighborhood	Elasticity estimated by MLIV			SARARIV
	Own-CPS area	2nd party-CPS area	Ratio[b]	Ratio[c]
1km	Does not converge		DA[a]	3.74
2km	Does not converge		DA	2.42
3km	-2.18%	-0.56%	3.89	3.57
4km	-2.27%	-0.49%	4.63	2.48
5km	Does not converge		DA	3.74
6km	-1.48%	0.23%	6.43	33.74
7km	-1.45%	0.46%	3.15	6.98
8km	Does not converge		DA	1.77
9km	-1.51%	0.28%	5.39	1.44
10km	-1.48%	0.12%	12.33	1.03

[a] DA stands for "does not apply"; [b]Absolute value; [c]Absolute value of ratio of coefficients weighted by the average of the corresponding covariate (own-CPS area or 2nd party CPS area).

Source: econometric estimations from goerreferenced database.

Table 3.9 Significance of coefficients capturing spatial autocorrelation for all neighborhood definitions considered

Neighborhood	λ	P
	24.61291***	-0.34173
1km	(6.25017)	(10.06356)
	21.67783***	0.97709
2km	(4.15643)	(4.5356)
	23.04613***	5.41916
3km	(4.00924)	(2.97012)
	16.52904***	49.54337***
4km	(3.83319)	(4.02888)
	17.35891***	67.32796***
5km	(2.61463)	(6.14064)
	19.22552***	59.65882***
6km	(3.24677)	(6.24347)
	20.47643***	48.90769***
7km	(4.3504)	(5.26322)
	21.79842***	42.21179***
8km	(5.3743)	(4.39695)
	22.30068***	38.77112***
9km	(6.06566)	(3.76929)
	18.22541**	40.46418***
10km	(5.66062)	(3.67409)

Source: econometric estimations from georreferenced database.

Table 3.10 Significance of instruments in the first stage of IV2S

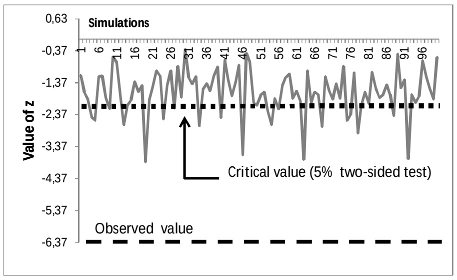
Neighborhood	Instrument / Regressand	Own CPS area	2nd-party CPS area
1 km	Average [a]	-2.1041***	-0.8743494**
		(0.4462724)	(0.2599857)
	Standard deviation [b]	4.257879***	4.530125***
		(0.8832771)	(0.739924)
2 km	Average	-10.28059***	-6.479743***
		(1.74228)	(1.505209)
	Standard deviation	22.07092***	14.83782 ***
		(2.697539)	(2.722084)
3 km	Average	-21.56356 ***	-30.38768***
		(3.930022)	(4.252629)
	Standard deviation	59.32349***	66.20961***
		(6.064563)	(7.213277)
4 km	Average	-38.8214***	-72.17131***
		(6.433395)	(9.136701)
	Standard deviation	106.7639***	164.17***
		(10.37601)	(15.37418)
5 km	Average	-79.26758***	-164.6196***
		(9.185195)	(16.63597)
	Standard deviation	177.8299***	358.5962***
		(15.25551)	(27.08287)
6 km	Average	-118.9652***	-364.9331***
		(11.69738)	(28.39658)
	Standard deviation	214.6019***	673.5819***
		(19.07325)	(42.28063)
7 km	Average	-157.1869***	-605.3273***
		(13.96997)	(41.52163)
	Standard deviation	246.2098***	1029.579***
		(21.96101)	(57.41509)
8 km	Average	-203.3107***	-897.5792***
		(16.01981)	(57.6751)
	Standard deviation	282.6451***	1448.057***
		(24.14526)	(74.58596)
9 km	Average	-246.9673***	323.9313***
		(17.66875)	(25.90327)
	Standard deviation	-1190.189***	1873.883***
		(74.97612)	(92.57371)
10 km	Average	-285.8206***	358.4***
		(19.08456)	(27.39676)
	Standard deviation	-1575.859***	2399.868***
		(94.97259)	(112.8326)

Source: econometric estimations (standard deviations in parenthesis). [a] Average of slope; [b] SD of slope.

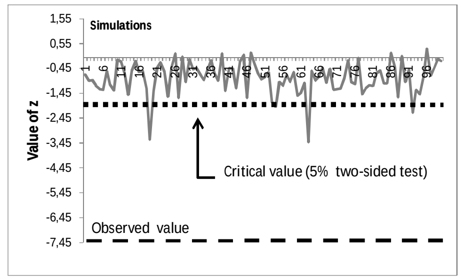
Panel 2 Selected results for the robustness test simulations*

(A) z = $\widehat{\beta}/\sigma_{\widehat{\beta}}$ for own-CPS area

2km neighborhood

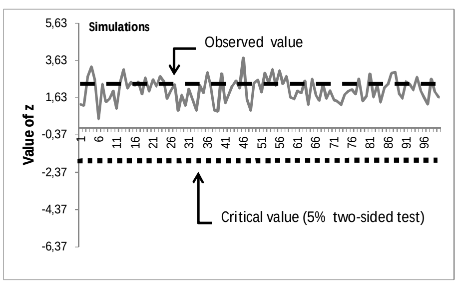


5km neighborhood

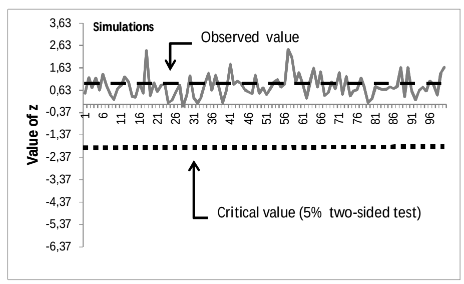


(B) z = $\widehat{\beta}/\sigma_{\widehat{\beta}}$ for second party CPS area

2km neighborhood



5km neighborhood



*only the negative critical value (-1.96) for the significance test of the coefficients of own and second-party CPS areas is indicated on the charts (as "critical value (5% two-sided test)"). The SARARIV estimates obtained with the observed dependent variable vector are indicated as "observed value".

3.7 Conclusion

The estimation results evidence that agents do not care for others, only for themselves. What has as a corollary that "others" care for themselves, so why do they do not prevent their neighbors from imposing them losses through accidental fire spreads?

Two mutually exclusive answers are possible:

(1) Farmers believe that the risk imposed by neighbors's fire use is negligible[78];

(2) The cost of preventing neighbors from causing losses to farmers, through accidental fire spread, is higher than the expected loss faced.

[78] What makes fire use optimal from the point of view of the neighbors considered as a single unit, a possibility that is equivalent to condition (2) of section 3.3.3.

The first possibility does not fit Paragominas' reality. Parcels treated with fire in 2010 have, within a distance of 2km from them, a median second-party CPS area that corresponds to 60.52 hectares of pasture (table A.3.13 of appendix A.3.3). The loss of effective rent, imposed by the accidental burning of such area, can be roughly estimated as amounting to US$2,235, as detailed in appendix A.3.3. A value that is not negligible, since it could buy 3.72 to 7.44 hectares of land in Paragominas (table A.3.15 of appendix A.3.3). Considering all parcels treated with fire and with at least 60.52 hectares of pastureland owned by neighbors within 2km, a total number of 160 parcels, the aggregated expected loss that results, US$357,610, is enough to buy 596 to 1,191 hectares of land.

The exclusion of possibility (1) leads to the conclusion that transaction costs matter. What can be only true due to (i) ill-defined property rights[79], owing to the lack of compliance with law that rules AFU (controlled burning law); and/or (ii) the difficulty to design an agreement that completely safeguards counterparts from uncontrolled fire spread[80].

The implication for policy is clear: it is necessary to design new institutional arrangements for the sharing of accidental fire risk among neighbors.

Additionally, the evidences point to a clear limitation of the "greening" process the municipality went through in face of the implications for ecosystems and also for society: sustainability, as reflected by the agricultural practices developed by farmers in 2010, can mean deforestation control but not, as the paper makes clear, control of accidental fires. What is not surprising in the light of the paper by Aragão and Shimabukuro (2010) where it is shown, for Brazilian Amazon, that decreasing forest suppression may not automatically result into falling fire incidence and thus, lower likelihood of major fire events.

As the authors claim, tools specifically targeted for affecting fire use practices must be designed. The paper provides crucial elements in this direction. It can be argued, in the basis of the results obtained, that even whether preventive measures, unobservable from satellite imagery, such as firebreaks (Bowman et al: 2008), are conducted by farmers, the protection

[79] I.e. it is not clear if it is the right to use fire, no matter the potential losses imposed to others, that prevails, or the right to be free from losses caused by fires started by others, no matter the cost, borne by fire starters, of avoiding such losses.

[80] What might derive from the difficulty to predict fire behavior, owing to the phenomena's sensitiveness to microclimate conditions. In such a complex environment, there is always room for opportunistic behavior (in the sense of (Williamson: 1996, section 3.2.4), such as blaming an unexpected change of the direction of wind (Cavalheiro: 2006), or an unexpected fall of humidity, for a fire spread that could be avoided if the fire was started farther from farm boundaries, closer to the interior of the farm. Other source for the cost of bargaining is the lack of monitoring and sanction instruments, as attested by Souza (2009, p.63), for the case of the AFU-based households located within Tapajós National Forest (northwest of Pará State, a protected area habited by over 7,000 families of smallholders).

they provide can be below the social desirable level because the full cost of accidental fires is not faced by farmers - when only part of the cost is faced, farmers' investment on prevention tends to find an equilibrium below the social desirable level (Shafran: 2008). Unless clear mechanisms for internalization are created, every farmer engaged on AFU will keep acting as if their neighbors are coresponsible for controlling fires they have not started, and a partial social protection against accidental fires will prevail.

The identification strategy performed well, correcting the overestimation of the effects of neighboring farms' CPS areas over the probability of the agents' to burn a parcel in the proximity.

The empirical exercise demonstrates that farm boundaries matter, having to be taken into account on further remote sensing studies of fire in the Brazilian Amazon. The knowledge accumulated up to the present time comes, overall, from statistical models that account only for biophysical and/or geographical factors as explanatory variables.

4 ACCIDENTAL FIRES AND LAND USE IN THE BRAZILIAN AMAZON: EVIDENCES FROM FARM-LEVEL DATA

Abstract

Is the risk of accidental fires, perceived by Brazilian Amazon farmers, taken into account on their land management decisions? The paper seeks to answer this question by laying on farm-level data, collected from a survey conducted on three municipalities of the state of Pará. Three are the main findings: (i) the incidence of fire on neighboring farms does not exert meaningful impact over how land is allocated among non-forest land uses; (ii) farms exposed to external sources of fire tend to allocate larger areas to secondary forest; (iii) the extension of farmland covered with pasture is not correlated with the exposure to external sources of fire, what suggests, in the light of previous research, that accidental fire risk is being underestimated by cattle ranchers of the study region.

4.1 Introduction

4.1.1 Accidental fires and land use

Land use decisions are generally made in the basis of expectations regarding crucial variables whose magnitude is a priori unknown (Chavas & Holt: 1990). The destruction of cultivation areas by accidental fires spreading from neighboring farms is an example of an uncertain event, whose causes are not fully under the control of the potential victims. Nevertheless, its consequences can be controlled whether land management is planned in compatibility with the true risk faced.

Nepstad et al (2001, p.399), in an evaluation of the socioenvironmental outcomes of fire use and deforestation in Brazilian Amazon, conjectures that farmers tend to avoid activities such as perennial crops, forest plantations and sustainable forest management, because of their high degree of fire susceptibility. The causality going from exposition to the risk of accidental fires to land allocation is also mentioned by Sorrensen (2004 p. 397), Mendonça et al (2004, p.90) and Arima et al (2007, p. 543). In fact, some authors see on fire-susceptible activities an opportunity to reduce the frequency of anthropogenic fire, and, consequently, the risk of accidental fires[81], whether their practice be stimulated through financial incentives (Barlow & Peres: 2004, p.11).

This “bet” implicitly assumes that policy tools can be used to make the investment on fire-susceptible land use profitable for farmers. Lowering investment’s cost is, however, not a sufficient condition. The risk of facing losses will remain unaltered in a level that can be high enough to prevent even the cheapest investment. It might just not pay-off to invest in perennials, after accounting for the risk in question. On the other hand, if the risk is systematically underestimated, farmers might start investing more heavily on perennials. The perceived vulnerability will consequently increase, but not necessarily in the amount needed to create incentives for breaking with fire-based land management. At least, not for all farmers whose decisions determine the true level of risk faced locally.

The design of policies for controlling the risk of accidental fires has, therefore, to be based on the assessment of the risk perceived by farmers. Is it relevant enough in order to affect the way their land is managed?

The paper seeks to answer this question by testing the hypothesis that accidental fire risk influence the way land is allocated among alternative uses in Brazilian Amazon. For this, a

[81]As Sorrensen (2009) makes clear, the accidental fire risk, or, in her terminology, “fire hazard”, is “the potential for anthropogenic fire to spread to proportions that are perceived harmful to a population and/or ecosystem.”

sample of farms located into three municipalities of the state of Pará is focused. Next subsection presents the database. It follows, subsequently, the exposition of the method and of the data. Results are analyzed in the fourth section and a brief conclusion follows.

4.1.2 The study region

The papers lays on RASDB survey data (chapter 1 of the thesis and Gardner et al: 2013), especially in what regards to land allocation, output and input price and farm location. Secondary data is also incorporated (see subsection 4.3 below).

Besides the wide array of evidence indicating that land use decisions in the Brazilian Amazon are being strongly shaped by market prices (Pffaf & Walker: 2010, Pfaff: 1999), our understanding of these relationships is limited by the scale at which data are available. The vast majority of the papers on the subject use aggregated socioeconomic datasets whose finest sampling level is the municipality (Caldas et al: 2007, p.88).

The paper is not subjected to this limitation. The two econometric models of land use are estimated from microdata at farm level.

4.2 Method

4.2.1 Theory

<u>4.2.1.1 General model</u>

Following Just et al (1983), Chamber & Just (1986), Moore & Negri (1997) and Feres et al (2009), the problem of allocating, among alternative land uses, an amount of farm land which is fixed in the short run, can be framed as follows.

$$\text{Max}_{\{a_1,\ldots,a_N\}} \sum_{i=1}^{N} \Pi_i(p_i, r, a_i, X)$$

$$\text{s.t.} \sum_{i=1}^{N} a_i = A$$

Where Π_i is the profit generated by the i-th land use, p_i the output prices vector, r the input prices vector, a_i the area allocated to the i-th land use and X, a vector of byophisical and socioeconomic factors that influence the magnitude of the profit obtained from the i-th land use. The total land available is represented by A. The restriction can be presented as an equality since the N land uses exhaust the possibilities of land allocation.

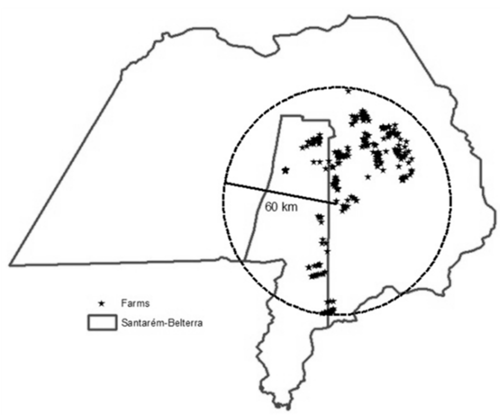
Assuming that the profit functions follow a normalized quadratic functional form (Shumway: 1983, p.749, Lau: 1976), the solution to the problem can be expressed as (Moore & Negri: 1997, p.33):

$$a_i^* = \alpha^i + \sum_{k=1}^{K} \delta_k^i p_k + \sum_{r=1}^{R} \theta_r^i w_r + \beta^i X + \gamma^i A, \qquad i = 1, \dots, N \quad (1)$$

Where all prices are specified in a common unit of value, a *numeráire*, in the case here, the market price of the least skilled labor (more detail on sections 4.2.1.3 and 4.3.2 below). The estimation of this equation from data covering a set of farms allows for identifying the main factors driving farmers' land use allocation decisions. Unfortunately, a crucial limitation of the survey data makes the task not straightforward.

The geographical domain spanned by the sampled farms, within each of the two study regions, is exiguous for Brazilian Amazon standards[82], as figures 11 and 12 show. For the Santarém-Belterra region, the largest distance between two farms is of 118 km. For Paragominas, this distance is equivalent to 185 km. Of course the fact of the two regions being separated in space for 600 km attenuates the implications in what regards to the variability of explanatory factors generally incorporated into land use analysis[83].

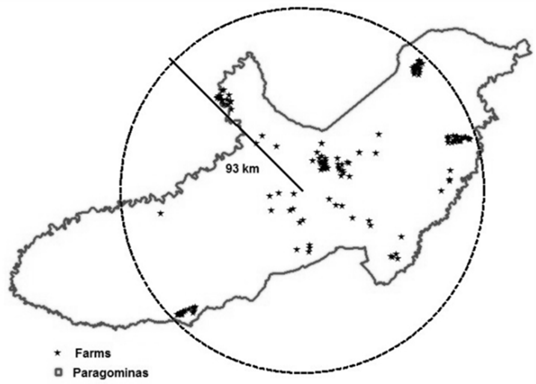
Figure 11 Santarém/Belterra sampled farms



[82] The average area of Brazilian Amazon municipalities is of 148 km^2 (2006 data from IBGE: 2010).

[83] The effect of this in terms of variability can be small, given that the sample can be seen as a composition of two groups of farms, within each variability tends to be small being relevant only when comparing two members of different groups.

Figure 12 Paragominas sampled farms



But for prices, the main explanatory variables on equation (1), the problem tends to be, nevertheless, relevant, given that the closer two farms are, the greater is the probability that they trade with common partners and face, thus, the same output and input prices[84]. This statement finds support on the "hotellian" localized competition models (Firgo: 2012, p.5), traditionally employed on the study of agricultural markets (Faminow & Benson: 1990, p.50), which assumes that "farmers differentiate between buyers [of outputs] on the basis of location" (Faminow & Benson: 1990, p. 50)[85].

It is necessary to highlight empirical evidences that support the idea of a positive relation of the distance between firms with the magnitude of the discrepancy of the prices for which they sell their output. Faminow & Benson (1990, tables 4 and 5), looking for the Canadian market for hogs, detect that pairwise price correlations decay with the distance between two regions. Firgo (2012, p.110), finds, on the Austrian retail market for gasoline, that "the degree of spatial differentiation [what comes out to be, on the author's model, equivalent to the least distance between two firms] increases prices, ceteris paribus." Goodwin & Schroeder (1991,

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[84] I.e., their trading networks share "nodes", to use the terminology of Blume et al (2009).

[85] There is an alternative way to state the argument of the paragraph. Let us assume that the Hotelling model applies but that the location decision is already made and cannot be reconsidered on the moment farmers choose the price for which they will try to sell their output (buy their inputs) – similarly to the two-stage conceptualization of the original model by Osborne and Pitchik (1987). If the prices for which two farmers sell their output (buy their input) differ only in function of the distance they are from the consumers (sellers), the closer they are from each other, the smaller will be the difference the prices they practice. To state it in another way still, the closer the farmers, the higher the probability that they belong to integrated markets, i.e, "markets in which price movements are highly correlated and prices differ exactly by transport costs (Faminow & Benson: 1990, p.56)."

p.463), detect, for the North-American regional cattle markets that the "spatial distance between the markets" decrease the "degree of price cointegration"[86] between the markets.
The problem under discussion is not a peculiarity of the database to be analyzed but a general characteristic of survey data[87], which generally have its spatial reach determined by the budget managed by researchers. Especially on regions ill-served by roads such as it is the case of Brazilian Amazon.
For addressing the issue under discussion, an alternative modeling approach, which lays not directly on prices, but on distances to markets, is explored. It is based on the recent literature on land use pioneered by Chomitz & Gray (1996). This has to be seen only as a complementary effort, given that prices cannot be a priori discarded as explanatory factors. They might contain relevant information, even under the geographical domain limitation discussed. Thus, in a try to keep consistency with the agricultural economics literature from which the econometric model (equation 1) originates, a standard set of equations, with prices on the right side, are also estimated. The two modelling approaches are presented in the next subsections.

4.2.1.2 Spatial interpolation approach

Farmers were asked, by RAS team, about the prices for which they sold their output on 2009, but only a small part of them answered the question[88], what applies analogously for the case of inputs bought. Under a spatial interpolation approach (Wackernagel: 1995, Gámez Martínez et al: 2000, Bourassa et al: 2005), each farm can be seen as a data collection point for prices. Taking into account the spatial correlation pattern found on the available information, it is thus possible to predict prices for the points where no data could be collected, considering, additionally, the distances from these points to the remaining points. This is basically what kriging, a spatial interpolation technique, does (Wackernagel: 1995, Bohling: 2005).
The values obtained should be seen not as estimates for effective market prices but for the prices farmers expect to face under the hypothesis that, for forming price expectations, they

[86] What can be understood, taking two markets at random, as the degree in which the temporal variation of the cattle price practiced on one of the markets explains the temporal variation of price on the other.
[87]Some examples confirm this. The household survey of Caldas et al (2007) covers farms distributed in an area of nearly 100 km^2. Bowman et al sampled 220 households within the national forest of Tapajós (FLONA). Collected data from 240 farms located into three municipalities of Rondônia state. Merry et al (2008, p.2394) is a counter-example, being that 900 km were covered by enumerators.
[88] See subsection 3.2 below.

ask geographically close farmers about the prices for which they have sold their outputs or bought their inputs. Spatial interpolated variables tend to vary smoothly along space except for the proximities of data collection points and especially close to the ones that informed a value (price) significantly different from the average (Wackernagel: 1995). What tends to reflect more the spatial distribution of the pre-selected collection points, i.e., in the particular case here, the sampled farms, than the true spatial distribution of prices, which tends to be affected by proximity to urban centers, transport modes (roads, for instance), facilities that process agricultural output, etc. To account for these factors is the goal of the second approach.

4.2.1.3 Distance approach

Chomitz and Gray (1996) pioneered a solution for working with data at fine spatial scales, such as remote sensing images. It basically consists on the hypothesis that, at such scales, prices varies only in function of distances to input/output markets. Next paragraphs introduce the approach.

Let the value received, by the farmer, as payment for the sale of one unit of the product k (the farmgate price) be given by $p_k = \overline{p_k} - v_k d_k$, where $\overline{p_k}$ is the market price, v_k the average transport cost by kilometer ($/unity/km) and d_k, the distance between the farm and the market for the product k. Assuming that markets are competitive, all farmers receive, by unit of k sold, the same value, $\overline{p_k}$. The price net of transport costs, however, varies with the location of farmers.

The same principle applies to input prices, with the difference that farmers are buyers and not sellers of inputs. This way, the price paid by an input r, taking into account the cost of transporting it to the farm, is $w_r = \overline{w_r} + s_r d_r$, where $\overline{w_r}$ is the price for which the input r is sold in the market, s_r the average cost of transport by kilometer ($/unit/km) and d_r, the distance between the farm and the market for input r.

In the basis of the discussion of the last two paragraphs, the general form of the econometric equation can be adapted to the distance-based approach, as follows.

$$a_i = \alpha^i + \sum_{k=1}^{K} \delta_k^i (\overline{p_k} + v_k d_k) + \sum_{k=1}^{K} \theta_k^i (\overline{w_r} + s_r d_r) + \beta^i X + \gamma^i A, \qquad i = 1, \dots, N \quad (1')$$

Or, subsuming the average transport costs (v_k's and s_r's) to the coefficients, i.e., taking $\delta_k^i v_k = \delta'^i_k$ and $\theta_r^i s_r = \theta'^i_r$, for all k and r:

$$a_i \ = \ \alpha^i \ + \ \sum_{k=1}^{K} \delta'^{i}_{k}\, d_k + \sum_{r=1}^{R} \theta'^{i}_{r} d_r \ + \beta^i X \ + \sum_{k=1}^{K} \delta^i_k\, \overline{p_k} + \sum_{r=1}^{R} \theta^i_k\, \overline{w_r} + \gamma^i A,$$

$$i \ = \ 1, \dots, N \qquad (1'')$$

The terms $\sum_{k=1}^{K} \delta^i_k\, \overline{p_k}$ and $\sum_{r=1}^{R} \theta^i_k\, \overline{w_r}$ can be omitted without any loss. Their values are fixed across producers, making them meaningless for cross-sectional analysis.

Equation (1'') allows for bringing into light the main limitation of the approach here presented in what regards the measurement of the influence of prices over land allocation. It consists on the fact that only for outputs whose correspondence with the set of trading locations or localized markets is univocal[89] it is possible to measure the influence of their transport cost over land use allocations. The same statement can be made for the case of inputs. Multiple correspondence between products and trading locations can be a fact, i.e., a farmer can sell a given product to (or buy a given input from) several markets. But it can also be imposed to insufficient information regarding the locations the farms attend in order to sell outputs or buy inputs.

Let it be assumed that there is a subset of outputs, of size q (<K) whose prices can be denoted by $p_l, \dots, p_{l+q}$, which, according to the available information are traded in the same market, which, for its turn, is indicated by the index "l". Equivalently, there are m inputs for which the available information indicates that they are traded in the same point in space, denoted by the index h. Additionally, it is known that q' outputs and m' inputs are traded, all of them, in a particular point in space, "u". Only for the remaining outputs and inputs (which do not belong to the subsets mentioned), the available information is rich enough to allow for identifying the location where each one of them is traded.

Equation (1''), under such conditions, takes the form bellow.

$$a_i \ = \ \alpha^i \ + \sum_{\substack{k \notin \{l,\dots,l+q\} \\ k \notin \{l',\dots,l'+q'\}}} \delta'^{i}_{k}\, d_k + \left(\sum_{k=l}^{l+q} \delta'^{i}_{k} \right) d_q + \sum_{\substack{k \neq m \\ k \neq u}}^{R} \theta'^{i}_{r} d_r + \left(\sum_{r=h}^{h+m} \theta'^{i}_{r} \right) d_m$$

$$+ \left(\sum_{k=l'}^{l'+q'} \delta'^{i}_{k} \right) d_u + \left(\sum_{r=h'}^{h'+m'} \theta'^{i}_{r} \right) d_u + \beta^i X \ + \gamma^i A (2)$$

Or, still:

[89] I.e., for outputs which are traded on one and only one point in space.

$$a_i = \alpha^i + \sum_{\substack{k \notin \{l,\dots,l+q\} \\ k \notin \{l',\dots,l'+q'\}}} \delta'^i_k d_k + \left(\sum_{k=l}^{l+q} \delta'^i_k \right) d_q + \sum_{\substack{r \notin \{h,\dots,h+m\} \\ k \notin \{h\prime,\dots,h\prime+m\prime\}}}^{R} \theta'^i_r d_r + \left(\sum_{r=h}^{h+m} \theta'^i_r \right) d_m$$
$$+ \left(\sum_{k=l'}^{l'+q'} \delta'^i_k + \sum_{r=h'}^{h'+m'} \theta'^i_r \right) d_u + \beta^i X + \gamma^i A \ (2')$$

It becomes clear that, under non-univocal correspondence between products and trading locations, some of the coefficients capture the aggregated effect of sets of outputs and sets of inputs. What it is identified is the effect (over the land area allocated for a given activity) of the proximity in relation to a trading location and not the effect of the price of a particular output or of a particular input.

Conclusively, by trying to solve the issue of the low variability of prices (subsection 4.2.1.1) one ends with a model whose explanatory power does not come, in any degree, from prices, but only from distances to relevant spots in space. This “face” of the distance-based land used models, which remains latent in the literature, once brought into light leave no doubt about the distinct nature of the two modeling approaches here considered.

The last step for having the model ready to estimation is writing the prices in function of a *numeráire*. The price paid by farmers for the least skilled labor will be taken as the measurement unit, once all farms interviewed by RAS team have at least one household located within their boundaries. This way, all farmers of the sample have access to low skilled labor at a negligible distance (once circumscribed to farm’s boundaries). The average cost of transport by kilometer (represented by the symbols “v_k” e “s_r” on equation (1)’) for each output and input, which is subsumed to the coefficients, is, therefore, normalized by the value of the *numerárie*.

4.2.1.4 Theoretical consistency restrictions

If the optimal allocations, represented by equation (1), are plugged into the restriction of the land allocation problem and derived in function of the parameters, the following conditions are obtained.

$$\sum_{i=1}^{N} \delta^i_k = 0 \,, k = 1, \dots, K \ (3)$$

$$\sum_{i=1}^{N} \theta^i_k = 0, r = 1, \dots, R \ (4)$$

$$\sum_{i=1}^{N} \beta_k^i = 0, \mathrm{j} = 1, \dots, \mathrm{J} \ (5)$$

$$\sum_{i=1}^{N} \gamma_k^i = 1 \ (6)$$

Optimal allocations must verify these restrictions. Their rationale is straightforward: if a price varies, incentivizing the farmer to increase (decrease) the amount of area allocated to a given crop, the amount of area dedicated to the remaining land uses must decrease (increase), owing to the fact that the total amount of land is fixed. The same can be said about the biophysical and socioeconomic factors behind the incentive to dedicate land for a given use. Only the effect of a variation on the total amount of land available (farm increases or shrinks) is peculiar because it does not have a differential effect over any land use, i.e., the incentive to develop all land uses are affected the same way. If land area grows in one hectare, the agent allocates 1/N extra hectare for each land use.

It is clear that, under restrictions 3 to 6, one of the coefficients that capture the effect of a given parameter over the area allocated to a given land use can be written as a linear combination of all remaining coefficients that capture the effect of the same parameter over the other land uses. The existence of linear dependent coefficients makes their joint estimation impossible owing to singularity. Only N-1 land use equations can be estimated, where N is the total number of land use categories considered. Next two subsections present a strategy to address this issue.

4.2.2 Estimation method

If a disturbance term is appended to the system of equations describing optimal land use allocations, whose general form is given by (1), a particular case of the system of seemingly unrelated regressions (SUR, Zellner: 1963), is obtained (Moore & Negri: 1997, p.34). To estimate it taking into account the correlations between disturbance terms that affect two different land uses (Moore & Negri: 1997, p.34), the technique of iterated SUR (ISUR) is selected given that it allows for efficient all-in-once system estimation in small samples (Cameron & Trivedi: 2008, p.157).

Only N-1 equations can be estimated owing to singularity, as already stated, but the coefficients of the non-estimated equation can be recovered from the theoretical consistency restrictions presented in the last subsection (Feres et al: 2009). This, however, will not be necessary once it is adopted the strategy to leave for the non-estimated equation an aggregation of land uses that can only be poorly explained by the model. Next subsection gives further detail.

4.2.3 Land uses modeled

Intercropping is commonly practiced in the study region for annual crops such as rice, cowpea, cassava and maize (Denich et al: 2005, Kato et al: 1999). But also for soybean it could be found evidences of intercropping with annuals (and also with fodder). Even being that it was collected data on intercropping schemes, only the minority of farms with annual crops has granted this information. Besides, only planted area was declared and not the whole size of the area allocated to annual crops (for instance, area kept under fallow is not available).

To address the imprecisions argued in the first paragraph, the optimal land allocation functions for annual crops have to be estimated in an aggregate basis. This requires a modification of the original model proposed by Chambers & Just (1986). Let the optimal allocation equation for a given crop be given by (1). Assuming that land uses i =1 to i = i_1 are related to crops, the equation for the whole crop area can be obtained summing specific crop equations:

$$\sum_{i=1}^{i_1} \mathrm{a}_i = \sum_{i=1}^{i_1} \alpha^i + \sum_{k=1}^{K} \mathrm{p}_k \left(\sum_{i=1}^{i_1} \delta_k^i \right) + \sum_{r=1}^{R} \mathrm{w}_r \left(\sum_{i=1}^{i_1} \theta_k^i \right) + X \sum_{i=1}^{i_1} \beta^i + A \sum_{i=1}^{i_1} \gamma^i \quad (7)$$

What leads to the following aggregated equation:

$$\mathrm{A}_{i_1} = \Lambda_0 + \sum_{k=1}^{K} \mathrm{p}_k \Delta_k + \sum_{r=1}^{R} \mathrm{w}_r \Theta_r + X \mathrm{B}_{K+r} + A \Gamma_{K+r} (7')$$

Where A_{i1} is the optimal area allocated for crops, Λ_0 the sum of intercepts across crop-specific equations, Δ_k the sum of farm area coefficients across crop-specific equations and similarly for Θ_k, B_{K+r} and Γ_{K+r}.

The estimation of the aggregated equation for crops generates, therefore, for all covariates, estimates for the sum of their crop-specific coefficients. The estimated coefficients measure, for instance, the impact of a relative price variation into the whole area allocated to annual crops. The term “aggregated coefficient” will be employed hereafter to refer to this “summed” effect.

A crucial point that must be highlighted is that the decision regarding the area to be allocated to land uses whose return is gathered along two or more years cannot be fully explained by spot prices, the main covariates of the general model. What seems to be the case for two of the land uses developed by RASDB farmers (chapter 1 of this thesis), perennial crops and forest plantations (silviculture). When considering such activities, farmers tend to look along time horizons that comprise more than a year and thus, price series matter (Knapp: 1987). The unavailability of this information makes the model a poor tool to explain the variation of both perennial crops and forest plantations across farms.

Having this in mind, it is possible to make a more solid step in the direction of the selection of the land use (or land uses) whose equation will not be directly estimated from ISUR. It seems reasonable to pick up a land use for which the model's performance tend to be poor, such as perennials and arboreal species.

The third convention regarding the definition of the land uses to be modeled is the distinction of primary and secondary forest, given their peculiar economic functions, especially the fact that fire and secondary vegetation tend to be connected through slash-and-burn agriculture.

Conclusively, the four modalities of land use to be explicitly modeled are: (i) annual crops, (ii) pasture; (iii) primary forest and; (iv) secondary forest.

The main drawback of the procedures described is that they make impossible to impose the symmetry of cross-price effects to estimation (in the sense, for instance, of Shumway: 1983 and of Moore & Negri: 1997, footnote 8)[90].

4.2.4 Measure for accidental fire risk

The risk of accidental fire faced by farmers is proxied by a binary variable indicating whether farmers have observed fire use in the neighboring farms from 2005 on. Fires started by farmers themselves are not accounted as a source of risk. Only exogenous (or external) sources of fire, thus matter.

4.3 Data

4.3.1 Data source and sample design

The reader is referred to chapter one of this thesis and to Gardner et al (2013).

4.3.2 Output and input price data

Total output on crops and manioc flour, the amount sold and the prices received were declared by survey respondents for the year of 2009. Missing data is an issue for the last

[90] What, is necessary to stress, comes solely from (i) the need to aggregate the areas dedicated annual crops except soybean and (ii) from the impossibility to explain land allocated to perennial crops and to forest plantations Even not being explicitly estimated, the coefficients of prices on the equation whose dependent variable is an aggregation of the areas of the land uses just mentioned, can be recovered from restrictions suggested by first order conditions of the land use allocation problem (Feres et al: 2009), as above mentioned.

variable: only 124 farms of the 487 full-sample observations have reported the price of manioc flour, the product with the largest number of price observations. To overcome this limitation, spatial kriging on the price of products with no less than 30 price observations is used. Secondary data coming from the Municipal Crop Survey (IBGE: 2009) was incorporated, taking as spatial reference the 100 km-nearest municipal capitals. That way it was possible to expand the spatial reach of kriging, which, for some products, was narrower than the spatial reach of the farm sample. The values obtained should be seen not as estimates for effective market prices but for the prices farmers expect to face wheter their expectations is based on the information they can get from their neighbors and for other geographically proximate sources.

For pasture, the price of cattle per kilogram, and not per head, is considered. What mitigates the discrepancy between the dominance of farms whose cattle raising aims at selling the calves (9 months aged, in average), among the group that declared a non-missing value for the price of cattle (82 of the 93, 88%, have calf selling as goal) and the fact that, in the sample used for econometric estimation, only 71 of the 137 (52%) farms with positive pasture area sells calves. Again, kriging proved necessary: cattle price is only observed for 89 of the 487 observations.

For the input prices, only hourly labor wage is available. Two worker categories could be identified on the data, representing low-skilled and high-skilled labor: soil preparation workers and machine (tractors, mostly) operators. Once again, kriging was employed: while, for the second kind of worker, wage observations amounted to 99 (out of 487), for the first one, they amounted to 33. The National Census of 2010 was used as source of secondary data for wages received by low-skilled rural workers and machine operators. This way the primary data could be enriched and the spatial reach of kriging could be made compatible with the geographical domain covered by the full sample of farms.

The price of low-skilled is used to normalize all other prices on the model that lays on spatial interpolated prices.

The information on the price of forest products, the third and last land use considered, is limited: the product with the largest number of price observations, Açaí (*Euterpe oleracea*), registered only 8 non-missing values. No alternative is left than leaving the explanation of forest area variation across farms to be explained solely by geographical variables, as if forest accumulated only on residual low-productive fractions of farm land area. This is consistent with the low frequency of transactions for forest products attested by the ignorable number of price observations recorded on the sample.

4.3.3 Market proximity metrics

On the distance-based approach, market proximity metrics are incorporated as means to identify the effect of locational determinants of the rent a farmer can derive from each of the land uses considered. For this strategy to work out perfectly, each metric must capture locational features that matter only for one specific land use being irrelevant for the other land uses (see equation 2' of section 4.2.1.3). What is, unfortunately, not fully possible when the information regarding the location of markets for outputs of each and every land use is only partially available.

With the available data, the market proximity metrics listed on the last column of table 4.1 could be generated. Some of them might capture the effect of locational factors that affect more than one land use, i.e., common sources of influence over a set of land uses. This is the case for the distance to roads and to municipal capitals (population centers), which capture the effect of proximity to markets for products such as crops, beef, timber coming from forest plantations and "natural" forests, and also non-timber forest products (NTFPs).

But others, such as distance to ports and slaughterhouses are more precise measures, as the next two subsections detail.

Table 4.1 Land uses and their respective ideal and feasible market proximity metrics

Land use	Output	Market	Ideal metric (distance to...)	Feasible metric (proxy) (distance to...)
Crops except for soybean [a]	Annual crops (excluding soybean)	Local	Main local markets for each annual crop	Roads; municipal capitals
	Perennial crops	Local	Main local markets for black peppers	Roads; municipal capitals
Soybean	Soybean	Local [a]	Main local markets for soybean	Roads; municipal capitals
		National [a]	Main national markets for soybean	Roads
		International [b]	Ports	Ports
Pasture	Cattle [b c]	Local	Slaughterhouses	Roads; municipal capitals; registered slaughterhouses
		National	Slaughterhouses	Registered slaughterhouses
Forest plantation	Timber [d]	Local	Timber processing factories; midlemen	Roads; municipal capitals
		National	Timber processing factories	Roads
Forest	Timber	Local [e]	Saw mills	Roads; municipal capitals
		National [e]	Main national markets for timber	Roads
		International [b]	Ports	Ports
	NTFPs [e]	Local	Main local markets for each NTFP	Roads; municipal capitals

Notes "a", "c", "d" and "e": the evidences from which the relevant markets were identified are presented in appendix A.4.1. [b] Please see subsections 4.3.3.1 and 4.3.3.2 below. Even being that there were six registers of international cattle exports, reported by RAS interviewees, according to the data from the Ministry of Development, industry and foreign trade (MDIC) there were no cattle exports from Paragominas, Santarém and Belterra, between January 2008 to December 2012.

Source: author's own-elaboration.

4.3.3.1 Distance to ports

The export/import database of the Ministry of Development and International Trade (ALICEWEB: 2013) links, for an exhaustive list of commodities, municipality of departure and port of arrival. Table 4.2 summarizes the main evidences collected.

Table 4.2 Share of ports on the exports of Paragominas, Santarém and Belterra, total value exported from January 2010 to October 2012

Municipality	Commodity / Port	Itaqui Port (São Luis. MA)	Vila do Conde (Bacarena. PA)	Santarém Port (Santarém. PA)	Other	Total (US$)
Paragominas	Timber	0	30.16%	0	1.86%	19,724,523.05
	Soybean	67.98%	0	0	0	41,869,612.07
	Other*	0	0	0	0	0
Santarém	Timber	0	0.28%	44.15%	0.17%	114,605,581.55
	Soybean	6.26%	0	49.04%	0.08%	142,321,144.98
	Other	0	0	0	0.02%	55,995.56
Belterra	Timber	0	0	0	0	0
	Soybean	0	0	0	0	0
	Other	0	0	0	100%	259

*"Other" does not contain cattle neither beef.

Source: AliceWeb (2013), database of exports by municipality. The total exported value of commodities from January 2010 to October 2012 was aggregated in the calculations of the shares. Total exported values (last column) are also aggregated.

Timber and Soybean are the main commodities exported by Paragominas and Santarém. Belterra exports are negligible[91]. While Paragominas exports exhibit a perfect univocal correspondence between ports and commodities (all soybean is sent to Itaqui Port and all timber to Vila do Conde Port), the inverse prevails for Santarém exports which are sent, regarding only timber and soybean, almost entirely, to the municipal port.

For the case of Paragominas, then, the distance between farms and the port of Itaqui can be used to identify specific determinants of the locational rents eventually obtained from the growing of soybeans. The same can be said for the distance between farms and the port of Vila do Conde, considering the locational rent of timber.

[91] Only rubber latex has been traded through mail agencies located in São Paulo, southeast of Brazil (more than 2.5 thousand km away from Belterra).

This "identification strategy" is not feasible for Santarém, owing to the fact the city has its own port which absorbs almost all tradeables. But, even not comprising the information needed to identify the locational rents of specific land uses, distance from farms to the port of Santarém concentrates non-negligible information to identify common determinants of the location rents potentially delivered by both land uses. It can, thus, be used as a measure to explain cross-sectional variation on the areas allocated for timber and soy and for other land uses.

The evidences just discussed find support in the literature. It is well documented that, for Brazilian Amazon, the international market has been a crucial driver of both soybean growing (Pacheco: 2012, p.828, Nepstad et al: 2006, p.3-4, Walker et al: 2009, p.741, Richards et al: 2012) and of timber extraction (Veríssimo et al: 1992, Rocha et al: 2006).

4.3.3.2 Distance to slaughterhouses

Bowman et al (2012) find statistically significant evidence for the influence of proximity to slaughterhouses over the size of farms' area allocated for pasture, what gives empirical support to other studies (Walker et al: 2009, p.736, Nepstad et al: 2006, Pacheco: 2012, Mertens et al: 2002, p.286). As stressed by Walker et al (2009), the main driver of the Amazonian "cattle economy" is the exports of the beef produced, on slaughterhouses, by the processing of the cattle grown on surrounding farms.

Only the location of slaughterhouses included on the Brazilian Federal Registry of Inspection (SIF) of the Ministry of Agriculture could be accessed. The fact of a facility being registered means that international sanitary standards are met. All slaughterhouses involved in transactions of outputs and/or inputs with interstate and/or international markets must be registered (MAPA: 2013, Brazil: 1952). What is not necessarily followed in practice (Smeraldi & May: 2008, p.24).

Non-SIF legal slaughterhouses tend work mostly with intra-state supplied cattle. Conclusively, the distortions introduced into estimations by the missing information about the location of non-SIF slaughterhouses can be (at least partially) mitigated by the metrics of proximity to local markets. The influence of non-SIF slaughterhouses that illegally obtain their cattle from other states can be controlled (partially, again) with metrics of proximity to national markets.

4.3.3.3 Travel time to urban centers

Farmers reported the amount of time spent to arrive at the near urban center. The question was answered for travels made with distinct transport modes during two generic seasons of the year, the rainy season ("summer") and the dry season ("winter"). The maximum amount of time across all the possible combinations between transport modes and seasons was converted into a common unit, minutes, to be incorporated in the model as an additional measure of proximity to local markets.

4.3.3.4 Fire use and fallow

Farmers have declared wether their neighbors have used fire from 2005 on (up to the year where the interview was done, 2010 or 2011). If the declaration is affirmative, it can be said that farmers are exposed to external sources of fire.

It is possible that farmers that generally employ fire have a different perception regarding the risk represented by external sources of fire. Thus, a dummy indicating whether interviewees have burned they land from 2005 on is added to the models. To have a measure for the magnitude of the eventual difference in perceived risk, it is also incorporated term between the binary variable indicating fire use by neighbors and the binary indicating fire use by the interviewee.

For farms engaged on slash and burn, the land allocated to secondary vegetation tends to be higher owing to the necessity of leaving part of the land idle under fallow. A dummy indicating the practice of fallow is included in order to control for this effect.

4.3.4 Further variables

Additional variables are commonly incorporated, as controls, on the two models estimated.

The slope of the terrain in a distance of 100 m from the points that represent sampled farms locations (headquarters) address the influence of topography over land use.

It is included a dummy that indicates with unitary value that the person that answered the questions regarding land use and production has educational level above the "lower secondary level of education", as defined by the International Standard Classification of Education (ISCDE 1997, OECD: 2011, p.9)[92]. The goal is to control for the level of human capital hold by the agents that make land use decisions (Vosti & Witcover: 1996, Alix-Garcia et al: 2005, p.229, Parman: 2012, p.17), what is related to the ability to obtain and analyze the relevant information (Parman: 2012, p.17, Schultz: 1975).

The information about the educational level was only collected for persons who lived in households located in the property. For the cases where the interviewee that answered the questions regarding land use and production does not live in the property, the educational

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*[92] *"Ensino fundamental"*, ideally designed for the ages of 6 to 14 years (British Council: ?).

level is, therefore, missing. There are, additionally, cases where educational level was not reported.

Farmers that do not own publicly recognized proofs of their ownership over the land farmed might not invest in land uses whose returns are not immediate (Araújo et al: 2011, Schuck: 2002, Kerekes et al: 2008) - such as perennial crops, forest plantations and even natural forest. What is driven by the positive probability of having the land claimed by government agencies or private entities, after the investment is made and before its return is fully collected by the farmer. Besides the incentive to invest, poor land tenure is also detrimental in terms of credit requisition, owing to the impossibility of using land as collateral (Kerekes et al: 2008).

Interviewees were asked about entitlement and the answers can be classified into three main categories. First, there are the cases where documents emitted by government agencies are hold[93], and, conclusively, land ownership is publicly recognized[94]. In the second place, there are a myriad of situations from complete lack of documentation to the holding of a “receipt (of purchase)” or a “land occupation certificate”, all of them cases where land ownership is not publicly recognized. The third possibility comprises missing or insufficient information, where the interviewee has not answered the question about entitlement, or his/her answer does not mention a particular document, or the interviewee rents the land (and therefore the question regarding land entitlement does not apply).

Farms classified in the first category are assigned with unitary value on the land entitlement dummy, the ones classified on the second category, with zero, and the remaining farms are treated as cases of missing data.

A dummy indicating the region where the farm is located, Paragominas municipality or Santarém and Belterra municipalities is also included in order to control for regional peculiarities.

Table 4.3 below lists all the variables of the interpolation-based model and table 4.4 the variables of the distance-based model. The respective statistical summaries are provided by tables 4.5 and 4.6.

[93] Belonging them to the federal level, to the state level or to the municipal level.

[94] The holding of a document issued by the governmental agency responsible for agrarian (land reform) settlements (INCRA) is included in this first category, for the farmers located in such settlements.

Table 4.3 Interpolation-based model variables

N	Variable	Notation	Measure for?	Unit
0	Area allocated to annual crops	a_ann	Land use decision (dependent variable)	hectares
0	Area allocated to pasture	a_pas	Land use decision (dependent variable)	hectares
0	Area allocated to primmary forest	a_pfo	Land use decision (dependent variable)	hectares
0	Area allocated to secondary forest	a_sfo	Land use decision (dependent variable)	hectares
1	Price of rice	p_rice	Distance to local and national markets	hours of low-skilled labor
2	Price of cassava flour	p_flou	Distance to local markets	hours of low-skilled labor
3	Price of maize	p_maiz	Distance to local and national markets	hours of low-skilled labor
4	Price of black pepper	p_pepp	Distance to international market	hours of low-skilled labor
5	Price of soybean	p_soy	Distance to international market	hours of low-skilled labor
6	Price of cattle	p_cattl	Distance to local markets	hours of low-skilled labor
7	Price of high-skilled labor	p_hlab	Scale economies on farming	hours of low-skilled labor
8	Total area of the farm	a_tot	Scale economies on farming	hectares
9	Slope of the terrain	slope	Production cost	percentage (100%)
10	Publicly recognized land ownership dummy (1 if farmer has it, 0 otherwise)	d_own	Inclination to invest on long-term projects; access to credit	binary
11	Educational level dummy (1 if the farmer has educational level above the lower secondary, 0 otherwise)	d_edu	Human capital	binary
12	Fire use by neighbors dummy (1 if neighbors have used fire from 2005 on, 0 otherwise)	d_fnb	Exposure to accidental fire risk	binary
13	Fire use dummy (1 if the farmer have used fire from 2005 on, 0 otherwise)	d_fow	Perceived exposure to accidental fire risk	binary
14	Interaction between dummies for farmer's fire use and neighbors' fire use	fire_int	Perceived exposure to accidental fire risk	binary
15	Fallow dummy (1 if farmer conducts fallow, 0 otherwise)	d_fall	Functions of secondary forest	binary

* all prices are normalized by the price of low-skilled labor.

Table 4.4 Distance-based model variables

N	Variable	Notation	Measure for?	Unit
0	Area allocated to annual crops	a_ann	Land use decision (dependent variable)	hectares
0	Area allocated to pasture	a_pas	Land use decision (dependent variable)	hectares
0	Area allocated to primmary forest	a_pfo	Land use decision (dependent variable)	hectares
0	Area allocated to secondary forest	a_sfo	Land use decision (dependent variable)	hectares
1	Distance to the nearest state or national road	rod_d	Distance to local and national markets	meters
2	Distance to the nearest municipal capital	cap_d	Distance to local markets	meters
3	Distance to the nearest (cattle) slaughterhouse	slg_d	Distance to local and national markets	meters
4	Distance to the port from which timber is exported	tim_d	Distance to international market	meters
5	Distance to the port from which soybean is exported	soy_d	Distance to international market	meters
6	Time taken to arrive at the nearest urban center (as reported by interviewees)	urb_t	Distance to local markets	minutes
7	Total area of the farm	a_tot	Scale economies on farming	hectares
8	Slope of the terrain	slope	Production cost	percentage (100%)
9	Region dummy (1 for Paragominas, 0 for Santarém-Belterra)	d_reg	Regions' peculiarities	binary
10	Publicly recognized land ownership dummy (1 if farmer has it, 0 otherwise)	d_own	Inclination to invest on long-term projects; access to credit	binary
11	Educational level dummy (= 1 if the farmer has educational level above the lower secondary, 0 otherwise)	d_edu	Human capital	binary
12	Fire use by neighbors dummy (1 if neighbors have used fire from 2005 on, 0 otherwise)	d_fnb	Exposure to accidental fire risk	binary
13	Fire use dummy (1 if the farmer have used fire from 2005 on, 0 otherwise)	d_fow	Perceived exposure to accidental fire risk	binary
14	Interaction between dummies for farmer's fire use and neighbors' fire use	fire_int	Perceived exposure to accidental fire risk	binary
15	Fallow dummy (1 if farmer conducts fallow, 0 otherwise)	d_fall	Functions of secondary forest	binary

Table 4.5 Statistical summary for interpolation-based model

Variable	N	Mean	Standard deviation	Minimun	Maximum
a_ann	160	38.46	138.35	0	1000.00
a_pas	160	10.23	26.46	0	196.00
a_pfo	160	39.09	127.12	0	1135.00
a_sfo	160	44.09	123.29	0	879.00
p_rice	160	0.15	0.04	0.06	0.20
p_flou	160	0.41	0.14	0.13	0.58
p_maiz	160	0.12	0.04	0.04	0.17
p_pepp	160	0.97	0.27	0.48	1.51
p_soy	160	0.20	0.06	0.07	0.27
p_cattl	160	1.04	0.29	0.42	1.40
p_hlab	160	1.80	0.45	0.78	2.84
a_tot	160	133.93	297.89	0.50	1999.00
slope	160	3.74	2.32	0.46	13.28
d_own	160	0.52	0.50	0	1
d_edu	160	0.13	0.34	0	1
d_fnb	160	0.78	0.42	0	1
d_fow	160	0.73	0.45	0	1
int_fire	160	0.63	0.49	0	1
d_fall	160	0.64	0.48	0	1

Table 4.6 Statistical summary for distance-based model

Variable	N	Mean	Standard deviation	Minimun	Maximum
a_ann	261	31.39	124.27	0	1000.00
a_pas	261	69.15	311.96	0	3090.00
a_pfo	261	98.32	512.84	0	6287.00
a_sfo	261	36.82	102.37	0	879.00
rod_d	261	6520.74	7503.09	0	28460.50
cap_d	261	36289.50	18494.96	4110.96	71961.10
slg_d	261	75735.54	46801.41	10785.22	169228.20
tim_d	261	108515.10	85761.47	9746.94	261905.70
soy_d	261	152129.60	144092.50	9746.94	434734.70
urb_t	261	129.78	87.84	3.00	420.00
a_tot	261	240.46	849.06	0.50	8702.00
slope	261	3.60	2.51	0	14.33
d_reg	261	0.36	0.48	0	1
d_own	261	0.53	0.50	0	1
d_edu	261	0.1455939	0.3533762	0	1
d_fnb	261	0.7624521	0.4263983	0	1
d_fow	261	0.7049808	0.4569276	0	1
int_fire	261	0.6130268	0.4879932	0	1
d_fall	261	0.6091954	0.4888681	0	1

4.3.5 Estimation sample and regression weighting

Models which explain the allocation of land solely from prices or from market proximity metrics can only be consistently tested with cross-sectional data whether there is a priori knowledge that the managers of the pieces of land captured by the data, i.e., the farmers, are in some non-negligible degree, influenced by market signals. A point that requires attention given that agricultural production for self-consumption (subsistence agriculture) is a recurrent land use in the RAS database.

In order to guarantee that the empirical exercise will capture market-integrated agents, only farmers that have sold, during 2009 (the most recent year covered by the interviews), a positive amount of some agricultural product (crops or cattle) or of timber or of some non-timber forest product (NTFP) will be part of the estimation sample.

Additionally, a farmer that rents part of his/her land for an afforestation/forest plantation project implemented by a private company[95] is left out of the estimation sample[96]. The reason is that the particular project bases the selection of land parcels into several criteria that are not necessarily related with market proximity, given the goal to occupy land not suitable for agriculture (Vale: 2011). For instance, land with highly degraded soil (low fertility) is preferred. Besides, the allocation of a given portion of land to silviculture, when coming from the arrangement in question, results from a bargain between two counterparts, what cannot be completely described by a model of optimal land allocation where the agent is a single atomic unit of decision.

On the estimations, observations receive a weight equivalent to the whole area of farm. Therefore, the coefficients capturing the impact of the proximity to specific markets over land allocation describes, overall, the behavior of the largest farms. The rationale of weighting regressions for the size of land is that the profitability of the land uses with the largest fixed costs[97] can be very low below a precise level of farm size.

The number of possibilities opened for the allocation of land tends to shrink with the size of farm owing to scale economies or, simply, to the lack of space. This is clearly not a matter of market proximity or of price discrepancy. It is, therefore, not enough to control for the effect of scale economy over the size of land dedicated to a given land use – what is done by the

[95] The farm in question is an outlier for silviculture area, with 5,600 hectares allocated to such land use.

[96] Vale, a major player in the international iron ore market, has created a unit for managing a project of afforestation/forest plantations in the state of Pará, named “Vale Florestar” (Vale: 2011). It consists basically in renting fractions of farm lands owned by second-parties, generally for 15 years (Vale: 2011, p.3), to plant native and/or exotic arboreal species (Vale: 2011).

[97] Such as soybean growing what generally lays on mechanized land clearing (Brown et al: 2004).

inclusion of farm land in the right side of equations. It is also necessary to control for the effect over the size of the land allocation “menu” evaluated by each farm. To give more importance for the farmers with the largest “menus” is a solution in such direction.

For the interpolation-based model, only farms belonging to the region of Santarém-Belterra are considered. The reasons lies on the fact that, for Paragominas municipality, the kriging of the soybean price is based on the price information declared for only five farmers. The resulting kriging domain comprises a band with 52 m of width. Beyond that, from the 250 farms eligible for estimation of the interpolation-based model, only 13% (33) belong to the municipality, guaranteeing that the exclusion just justified cannot distort results.

4.4 Results and discussion

Table 4.7 Results for the interpolation-based model (Santarém-Belterra region only)

	a_ann	a_pas	a_pfo	a_sfo
p_rice	665.05124	671.41444	-1.375e+04***	1.243e+04***
	(1933.16722)	(570.06434)	(2577.07699)	(1866.25083)
p_flou	935.92774	-1.334e+03***	-1090	1474.17857*
	(686.18166)	(202.34551)	(914.73875)	(662.42955)
p_maiz	1520.82696	-81.57048	1.158e+04***	-1.306e+04***
	(2309.08631)	(680.9177)	(3078.20925)	(2229.15752)
p_pepp	-92.93914	333.61911***	577.43531*	-812.60207***
	(183.32822)	(54.06096)	(244.39218)	(176.98233)
p_soy	3759.71763	3245.07552***	-4006	-2957
	(1982.511)	(584.61515)	(2642.85648)	(1913.88658)
p_cattl	-521.48479*	-207.77448**	33.62364	701.83186**
	(255.75993)	(75.42008)	(340.94983)	(246.90683)
p_hlab	-572.62605***	-185.92691***	978.19384***	-223.89817*
	(104.70367)	(30.87567)	(139.57894)	(101.07937)
a_tot	0.48086***	-0.01103	0.07732**	0.45303***
	(0.02071)	(0.00611)	(0.02761)	(0.01999)
slope	22.67039***	-2.28153	-23.48392***	3.18124
	(4.28624)	(1.26395)	(5.71392)	(4.13787)
d_own	-44.19739	9.9077	14.46957	19.39579
	(25.92208)	(7.64407)	(34.55635)	(25.02479)
d_edu	-37.29172	45.17096***	102.77263**	-110.52794***
	(25.4247)	(7.49739)	(33.89329)	(24.54462)
d_fnb	70.30847**	-22.68344**	-115.10667***	68.20124**
	(25.67408)	(7.57093)	(34.22574)	(24.78537)
d_fow	69.3706	7.81745	-175.84141	99.64399
	(76.21899)	(22.47593)	(101.60643)	(73.58068)
int_fire	-73.18705	11.99394	81.81019	-26.54805
	(70.49917)	(20.78923)	(93.98142)	(68.05885)
d_fall	49.03973	-17.79871	14.76236	-45.82501
	(36.92552)	(10.88883)	(49.22487)	(35.64735)
_cons	73.17013	45.88569*	-267.03027**	141.17127*
	(68.64373)	(20.24209)	(91.50796)	(66.26764)
N	160	160	160	160
R^2	0.90311	0.52937	0.7872	0.88627
p-value. chi ^{2}	< 0.1%	< 0.1%	< 0.1%	< 0.1%

Source: econometric estimations from RASDB.

Table 4.8 Results for the distance-based model

	a_ann	a_pas	a_pfo	a_sfo
rod_d	-0.004	-0.03135***	0.02246***	0.00223
	(0.00391)	(0.00483)	(0.00652)	(0.00243)
cap_d	-0.00387*	0.01551***	-0.00571	-0.00423***
	(0.00179)	(0.00221)	(0.00298)	(0.00111)
slg_d	-0.00364***	0.00469***	0.00123	-0.0011
	(0.00096)	(0.00119)	(0.0016)	(0.0006)
tim_d	0.00195*	0.00178	-0.00214	-0.00162**
	(0.00093)	(0.00115)	(0.00155)	(0.00058)
soy_d	-0.00118	-0.00730***	0.00645***	0.00043
	(0.00066)	(0.00081)	(0.0011)	(0.00041)
urb_t	0.17009	0.41574	-1.23454*	0.92271***
	(0.37476)	(0.46323)	(0.6256)	(0.23344)
a_tot	-0.01462	0.26715***	0.70972***	0.01542
	(0.01356)	(0.01676)	(0.02263)	(0.00844)
slope	-0.35895	-42.32132***	29.70412*	11.03279*
	(6.96474)	(8.60882)	(11.62647)	(4.33829)
d_reg	40.04401	2092.35205***	-1.607e+03***	-56.62807
	(255.05793)	(315.26603)	(425.7765)	(158.87363)
d_own	-106.92827**	-181.40429***	132.34457*	116.15812***
	(39.80432)	(49.20039)	(66.44664)	(24.7938)
d_edu	24.31415	177.75561**	-179.55680*	-11.90774
	(44.3257)	(54.78907)	(73.99433)	(27.61014)
d_fnb	84.21151	17.5391	-182.10894*	119.65147***
	(49.5104)	(61.19766)	(82.64933)	(30.83965)
d_fow	-228.00978***	797.90410***	-488.13249***	-57.61808
	(64.56784)	(79.8095)	(107.78519)	(40.21881)
fire_int	-106.09458	-849.49454***	1009.01104***	-111.52407*
	(83.66752)	(103.41779)	(139.66891)	(52.11586)
d_fall	80.08046	4.19069	-7.78963	-70.77917
	(68.10448)	(84.18099)	(113.68902)	(42.42176)
_cons	710.50356***	-329.13013***	-689.51938***	315.98678***
	(71.82763)	(88.78302)	(119.90421)	(44.74088)
N	261	261	261	261
R^2	0.45334	0.93131	0.96886	0.63537
p-value. chi ^{2}	<0.1%	<0.1%	<0.1%	<0.1%

Source: econometric estimations from RASDB.

4.4.1 Results for the interpolation-based model

The fact of fire have being used by neighbors is positively correlated with the area covered by annual crops. This might be capturing the fact that fire use tends to cluster in space where there is incentive to grow annual crops through slash-and-burn (chapter 3 of this thesis).

Secondary forest seems to be used as a protection barrier to accidental fires. Even controlling for determinants of the incentive to replace forestland for agricultural activities (prices and slope), secondary forest tends to cover a large area on farms exposed to external sources of fire. It looks inconsistent with such evidence the fact that the area allocated to primary forest is positively correlated with fire use in the neighborhood.

The effect of external sources of fire is not statistically significantly different between farmers that have used fire from 2005 on and farmers that have not used fire.

The price of soybean do not exerts a significant influence over the size of land allocated to annual crops. Contrariwise, the area allocated to pasture is positively correlated with such price.

The price of cattle, for its turn, has no statistically significant effect over the amount of land allocated to pasture but it is negatively correlated with the amount of land allocated to soybean growing. It also functions as a factor that favors the allocation of area to forest, what contradicts the dominant consensus pointing to cattle ranching as the main driver of deforestation for Brazilian Amazon (Pacheco et al: 2012, p. 869-870, Margulis: 2003, Faminow: 1997).

Pastureland is negatively correlated with cattle price and with the exposure to external sources of fire and positively correlated with the price of soybean. These counterintuitive results can be driven overall by the small explanatory power the model reveals to have for pastureland, compared to the other three land uses explained, as the R^2 values attest.

The price of maize has a positive impact over the amount of land kept as forest.

The smaller the slope, the larger the amount of land kept as primary forest what is also contra-intuitive, given that agricultural profitability tends to decay with the level of slope (Robalino & Pfaff: 2011). It is possible that slope is capturing the effect of uncontrolled factors.

Overall, the results yielded by the interpolation-based model are counterintuitive.

4.2 Results for the distance-based model

The land area allocated to annual crops is negatively correlated with the exposure to external sources of fire. This evidence has to taken with caution, given that the fit to data of the equation implicated is considerably worse compared to what could be achieved with the interpolated-based model.

Farmers act as if the external sources of fire could not represent a material risk to pastureland, since a statistically significant and positive correlation is found between the two variables. What may be due to the practice of burning pastures overrunned with weeds (chapter 3 of this thesis), as the also positive and statistically significant correlation with own-fire use suggests.

Again, secondary forest tends to spread along larger areas on the farms exposed to external sources of fire, even controlling for the distance to timber exportation ports and other factors that drive the incentive to deforest/preserve. And the area taken by secondary forest is negatively impacted.

Proximity to markets exerts statistical significant influence over the sampled farmers land use decisions.

Farmers closer to national or state roads, a proxy for distance to national markets, tend to allocate larger areas to pasture and smaller areas to primary forest.

There is no clear evidence regarding the proximity to local markets, as measured by the distance to municipal capitals and by the travel time to the closest cities declared by interviewees. The first measure has significant and positive influence over the amount of land area allocated to annual crops and to pasture and a significant and negative influence over the amount of land area allocated to secondary forest. No significant effect was found over primary forest. What contradicts the Thunian model (Angelsen: 1994).

Distance to slaughterhouses that met international sanitary standards affects negatively the amount of land dedicated to pasture, as expected, and decreases the area allocated to annual crops, what suggests the two land uses compete for land.

Proximity to ports through which soybean is exported is a factor that significantly influences the allocation of land to non-forest land uses. As expected, proximity to ports which are relevant “sinks” of timber result into larger land areas allocated to forests, but only to secondary forests.

The slope of the terrain has positive influence over the amount of land allocated to primary and secondary forest, what is intuitive (Robalino & Pfaff: 2011), and negative over the size of pastureland.

Ownership of land it increases the area allocated to forests (primary and secondary) and decreases the area allocated to annuals and to pasture.

Farms where the interviewee has an educational level above the lower secondary allocate larger areas to pastureland and smaller areas to primary forest.

The practice of fallow do not have statistically meaningful influence, what can be due to colinearity with the dummy capturing the use of fire.

External sources of fire exert an influence of larger magnitude over the amount of land allocated to pasture and to secondary forest among farmers that have not used fire from 2005 on, compared to the group of farmers that have used fire. This is what the statistical significance of the interaction term, on the equations explaining the land uses mentioned, indicates.

4.4.3 Comparing models

The interpolation approach gave support to a better fit of the equation for annual crops and the distance approach proved to be better for explaining the pasture area. Such is the main difference between models.

Spatial interpolation of prices presupposes that price variations across farms have explanatory power over discrepancies observed for land allocation. However, as initially exposed (section 4.2.1.1), such power tends to be small whether the farmers sell their output or buy their inputs on common markets, trading with common partners. Notwithstanding, a non-negligible power is guaranteed by the reflection, on the prices reported by interviewees, of the transport costs directly paid by them, or extracted from them by the middlemen that pay a price below the market (in order to cover his/her costs). This is attested by estimations, which reveal statistical significant correlations between prices and land areas allocated for specific activities.

4.5 Conclusion

The results obtained lead to the conclusion that the incidence of fire on neighboring farms does not exert meaningful impact over how land is allocated among non-forest land uses. But, in what regards to how farm land is shared between secondary forest and other land uses, it was found a clear evidence for dedicating larger areas to the first possibility for farms exposed to external sources of fire.

The rejection of the hypothesis that the extension of farm land occupied with pasture is influenced by the risk of accidental fires, by the distance-based model, suggests the conjecture that such risk is being underestimated by farmers of Santarém, Belterra and Paragominas. The numbers for the amount of pasture and the length of fences yearly lost in the Amazon, calculated by Mendonça et al (2004), are clear reasons for which agents more exposed to external sources of fire should keep smaller areas of pasture. Except, of course, for farms where the pasture is so overruned by weeds that accidental fires can be seen as cost-free opportunities for converting them.

5 CONCLUDING REMARKS

5.1 General results

The first essay demonstrates, at the theoretical level, that the profitability of S&BA is governed by the trade-off between cost-free fertilization through the burning of secondary vegetation and idleness of the land.

The trade-off, however, temporarily ceases to exist, when the length of fallow is suddenly reduced, what increases the profit beyond its long-run level (assuming that unfavorable price variations do not manifest). Whether the previous fallow duration is long enough, the overshoot can generate a cash surplus that can be used to finance (at least partially) the transition to a fire-free agriculture.

The enunciation of this possibility and the empirical validity of the cost-free-fertilization-land-idleness-trade-off constitute the main results of the first essay.

The hypothesis of non-internalization of potential damages caused to others through the loss of control over fire is not refuted by georeferenced data for the municipality of Paragominas and for the year of 2010. The randomization of fire detections was conducted as a robustness test that confirms that farmers only care, considering all the crops, pasture and silviculture areas within the radius of reach of accidental fires, to the fraction of their property.

On the third essay, land allocation models pertaining to two different traditions of economics, agricultural economics and land use economics, are taken as basis to estimate the impacts of exposition to accidental fires. It is concluded that fire incidence on the neighborhood exert meaningful impact only over how land is allocated between forest and non-forest land uses. The impact over the allocation among non-forest land uses is not clear. It can only be claimed that cattle ranchers do not seem to adjust their pasture area to the risk of having it accidental burned by external sources of fire.

5.2 Main results and policy implications

In summary, it can be concluded that:

(1) The success of governmental programs that provide partial financial support to the shift to fire-free agriculture - in which, for instance, fertilizers, must be purchased by farmers - depends on the duration of the fallow previously practiced by farmers. The larger this duration, the greater the likelihood of success, given that the higher will be the profit obtained in the year before the adoption of the new techniques (abstracting, again, from unfavorable price variations);

(2) No convincing evidences were found in what regards to the possibility that production losses eventually induced by accidental fires can be a strong enough motivation to drive the farmers, in the municipalities investigated, to break with the agricultural use of fire.

The second result cast a shadow of doubt over the contribution of the mandatory burning permit policy and of its monitoring, as well as informal agreements among neighbors, in what regards the accountability of fire users. Would these institutional arragements be working as they were designed for, farmers would care for burning their neighbors' land, i.e. (at least partial) internalization would be evidenced by the empirical exercizes.

5.3 Future research

Two avenues for future research have been opened:

1 To combine resource economics and computer models to study the non-steady state dynamics of secondary vegetation management by S&BA farmers;

2 To evaluate evidences for the internalization of fire externalities from satellite imagery merged with ground-based surveys, focusing on other regions of the Brazilian Amazon.

REFERENCES

ABRAMOVAY, R.(1992) **Paradigmas do Capitalismo Agrário em Questão**. 2. ed. São Paulo: Hucitec/Edunicamp.

AKERLOF, G.A. (1997) Social distance and social decision. **Econometrica**, Vol. 65, No. 5 (Sep., 1997), pp. 1005-1027.

ALENCAR, A., NEPSTAD, D., DIAZ, M. C (2005) Forest Understory Fire in the Brazilian Amazon in ENSO and Non-ENSO Years: Area Burned and Committed Carbon Emissions. **Earth Interactions**. Volume 10 (2006). Paper No. 6.Page 2.

ALENCAR, A.,ASNER, G.P., KNAPP, D., ZARIN, D. (2011). Temporal variability of forest fires in eastern Amazonia. **Ecological Applications**, 21(7), 2011, pp. 2397–2412.

ALICEWEB (2013) International trade online database of the Brazilian Ministry of Development, Industry and Foreign Trade. http://aliceweb.desenvolvimento.gov.br/

ALIX-GARCIA, J., DE JANVRY, A., SADOULET, E. (2005) A Tale of Two Communities: Explaining Deforestation in Mexico.**World Development** Vol. 33, No. 2, pp. 219–235, 2005

ALMEIDA, O. T. & UHL, C. (1995) Developing a quantitative framework for sustainable resource-use planning in the Brazilian Amazon. **World Development**, v.23, p.1.745-1.764, 1995.

ALVES, R. N. B. (2007) O Trio da Produtividade na Cultura da Mandioca. Belém, PA: Embrapa Amazônia Oriental, 2007. http://www.cnpma.embrapa.br/boaspraticas/download/Trio_Produtividade_Cultura_Mandioca.pdf

AMACHER, G. S. OLLIKAINEN, M., KOSKELA, E. (2009) **Economics of forest resources**. Cambridge, US: the MIT Press.

ANGELSEN, A. (1994) **Shifting Cultivation Expansion and Intensity of Production: The Open Economy Case.** Chr. Michelsen Institute for Development Studies and Human Rights. Working Paper WP 1994:3. Bergen, December 1994. http://bora.cmi.no/dspace/bitstream/10202/355/1/WP1994.3%20Arild-07192007_7.pdf

ANSELIN, L. & BERA, A. (1998). “Spatial dependence in linear regression models with an introduction to spatial econometrics.” In: Ullah A, Giles DE (ed) **Handbook of Applied Economic Statistics** 237-289, Marcel Dekker, New York

ARAGÃO, L., & SHIMABUKURO,Y. E. (2010) The incidence of fire in Amazonian forests with implications for REDD. **Science** 328:1275-1278.

ARAÚJO, C., BONJEAN, C. A., COMBES, J.-L., MOTEL, P. C., REIS, E. J. (2011) Does land tenure insecurity drives deforestation? **CERDI, Etudes et Documents**, E 2010.13. Available at: http://www.cerdi.org/uploads/ed/2010/2010.13.pdf

ARIMA, E. Y., C. S. SIMMONS, R. T. WALKER, COCHRANE, M.A. (2007) Fire in the Brazilian Amazon: a spatially explicit model for policy impact analysis. **Journal of Regional Science** 47:541-567.

ARTHUR, B. W. (1989) Competing Technologies, Increasing Returns, and Lock-In by Historical Events **The Economic Journal**, Vol. 99, No. 394 (Mar., 1989), pp. 116-131.

ASSUNÇÃO, J., GANDOUR, C. E., ROCHA, R. (2012) **A Queda do Desmatamento na Amazônia Brasileira: Preços ou Políticas?** Sumário Executivo Climate Policy Initiative Rio de Janeiro. Núcleo de Avaliação de Políticas Climáticas, PUC-Rio Janeiro 2012. http://climatepolicyinitiative.org/wp-content/uploads/2012/03/Deforestacion-Precos-ou-Politicas-Sumario-Executivo-Portuguese.pdf

AYRES, R. & AYRES, E. (2010) **Crossing the energy divide**. Pearson Education.

BACEN (2013) Time series online data. **Sistema gerenciador de séries temporais (SGS)**. Série 3691 (PTAX800). Available at http://www4.bcb.gov.br/pec/series/port/aviso.asp. Central Bank of Brazil

BARLOW, J., PARRY, L., GARDNER, T.A., FERREIRA, J., ARAGÃO, L. E. O.C., CARMENTA, R., BERENGUER, E., VIEIRA, I. C. G., SOUZA, C., COCHRANE, M.A (2012). The critical importance of considering fire in REDD+ programs. Paper in press. **Biological Conservation.**

BARLOW, J., PERES, C. A. (2004) Ecological responses to El Nino-induced surface fires in central Brazilian Amazonia: management implications for flammable tropical forests. **Phil. Trans. R. Soc. Lond. B.**

BARONA, E. RAMANKUTTY, N., HYMAN, G. COOMES, O. (2010) The role of pasture and soybean in deforestation of the Brazilian Amazon. The role of pasture and soybean in deforestation of the Brazilian Amazon. **Environ. Res. Lett.** 5 (2010) 024002 (9pp).

BAUMOL, W. J. & OATES, W. E. (1988) **The theory of environmental policy**. Second Edition. Cambridge University Press.

BLANCO, H., LAL, R. (2008) **Principles of soil conservation and management.** Springer.

BLAUG, M. (2002) **Teoría económica en retrospección.** México: Fondo de Cultura Económica.

BOHLING, G. (2005) **Kriging.** Kansas Geological Survey. Available at http://people.ku.edu/~gbohling/cpe940/Kriging.pdf

BÖRNER, J-C, MENDOZA, A., VOSTI, S.A. (2007) Ecosystem services, agriculture, and rural poverty in the Eastern Brazilian Amazon: Interrelationships and policy prescriptions. **Ecological Economics** 64 356-373.

BÖRNER, J-C. (2006) **A bio-economic model of small-scale farmers' land use decisions and technology choice in the eastern Brazilian Amazon.** PhD Dissertation, Bonn University, Germany.

BOSERUP, E. (1965). **The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure.** Chicago: Aldine. London: Allen & Unwin.

BOURASSA, S. C., CANTONI, E., HOESLI, M. (2005) Spatial dependence, housing submarkets and house prices.Research Paper N° 151, **FAME - International Center for Financial Asset Management and Engineering**.

BOWMAN, M. S., AMACHER, G. S.,MERRY, F. D (2008). Fire use and prevention by traditional households in the Brazilian Amazon. **Ecological Economics** 67 (2008) 117 – 130.

BOWMAN, M. S., SOARES-FILHO, B., MERRY, F. D., NEPSTAD, D. C., RODRIGUES, H., ALMEIDA, O.T (2012) Persistence of cattle ranching in the Brazilian Amazon: A spatial analysis of the rationale for beef production. **Land Use Policy** 29 (2012) 558–568.

BRAZIL (1952) Sanitary law for slaughterhouses.Decreto nº 30.691 de 29 de março de 1952. Available at: http://www.planalto.gov.br/ccivil_03/decreto/1950-1969/D30691.htm http://www.agricultura.gov.br/arq_editor/file/Aniamal/MercadoInterno/Requisitos/RegulamentoInspecaoIndustrial.pdf

BRITO, B. SOUZA JR. C., AMARAL, P. (2010) **Reducing emissions from deforestation at municipal level**: a case study of Paragominas, eastern Brazilian Amazon. Everything is connected. Climate and Biodiversity in a Fragile World. http://ukinbrazil.fco.gov.uk/en/about-us/working-with-brazil/everything-connected1

BROWN, C.J., JEPSON, W., PRICE, K.P.(2004) Expansion of mechanized agriculture and land cover change in Southern Rondônia, Brazil. **Journal of Latin American Geography** 3, 96–102.

CALDAS, M., WALKER, R., ARIMA, E., PERZ, S., ALDRICH, S., SIMMONS, C. (2007) Theorizing Land Cover and Land Use Change: The Peasant Economy of Amazonian Deforestation. **Annals of the Association of American Geographers**, Vol. 97, No. 1 (Mar., 2007), pp.86-110.

CAMERON, A.C & TRIVEDI, P.K. (2009) **Microeconometrics using STATA**. Stata Press Publication, College Station, Texas.

CARDOSO, M. F., G. C. HURTT, B. MOORE, C. A. NOBRE, AND E. M. PRINS. (2003) Projecting future fire activity in Amazonia. **Global Change Biology** 9:656-669.

CARMENTA, R., L. PARRY, A. BLACKBURN, VERMEYLEN, S., BARLOW, J. (2011). Understanding human-fire interactions in tropical forest regions: a case for interdisciplinary research across the natural and social sciences. **Ecology and Society** 16(1): 53.

CARPENTIER, C. L., VOSTI, S. A., WITCOVER, J. (2000) Intensified production systems on western Brazilian Amazon settlement farms: could they save the forest? Agriculture, **Ecosystems and Environment** 82 (2000) 73–88

CAVALHEIRO, K. (2004) **Community fire management in the Maraba region, Brazilian Amazonia**. PhD Dissertation. University of Florida, Gainesville,Florida, USA.

CHAMBERS, R. G., JUST, R. E. (1989) Estimating Multioutput Technologies. **American Journal of Agricultural Economics**, Vol. 71, No. 4 (Nov., 1989), pp. 980-995

CHAVAS, J.-P, HOLT, M. T. (1990) Acreage decisions under risk: the case of corn and soybeans. **American Journal of Agricultural Economics**, Vol. 72, No. 3 (Aug., 1990), pp. 529-538

CHIANG, A. & WAINWRIGHT, K. (2002) **Fundamental Methods of Mathematical Economics**. McGrall-Hill.

CHOMITZ, K.M. & GRAY, D.A. (1996) Roads, Land use and deforestation: A Spatial Model Applied to Belize. **The World Bank Economic Review**: n°3, 487-512.

COASE, RONALD H. (1960). "The Problem of Social Cost". **Journal of Law and Economics** 3 (1): 1–44

COCHRANE, M. A (2009). Fire, land use, land cover dynamics, and climate change in the Brazilian Amazon. In Cochrane, M. A., **Tropical fire ecology: climate change, land use and ecosystem dynamics.** Chapter 14. Springer, Praxis Publishing, UK.

CONLEY, T.G. & UDRY, C. R. (2008) Learning About a New Technology: Pineapple in Ghana. **American Economic Review**, American Economic Association, vol. 100(1), pages 35-69, March.

COOMES, O. T., GRIMARD, F., BURT, G. J. (2000). Tropical forests and shifting cultivation: secondary forest fallow dynamics among traditional farmers of the Peruvian Amazon. **Ecological Economics** 32 (2000) 109–124

CONRAD, J.M. (1999) **Resource economics**. Cambridge: Cambridge University Press.

COSTA, F. A. (1995) O investimento na economia camponesa: considerações teóricas. **Revista de economia política**, vol. 15, n. 1 (57), Janeiro-Março 1995.

COSTA, F. A. (2004) Path dependency e a transformação agrária do bioma amazônico: o sentido econômico das capoeiras para o desenvolvimento sustentável. **Novos Cadernos NAEA**. v. 7, n. 2, p. 111-158, dez. 2004, ISSN 1516-6481.

CRAVO, M.S., CORTELETTI, J., NOGUEIRA, O.L., SMYTH, T. J., SOUZA, B. D. L. (2005), **Sistema Bragantino: Agricultura Sustentável para a Amazônia.** Embrapa Amazônia Oriental Belém, PA, 2005. http://ainfo.cnptia.embrapa.br/digital/bitstream/item/25752/1/Doc218.pdf

CREWS, K.A. AND WALSH, S.J. (2009) Remote Sensing and the Social Sciences In Warner, T. A., Nellis, M. D., Foody, G.M. (Editors) Remote Sensing and the Social Sciences. **The Sage Handbook of remote sensing**. SAGE Publications. London.

DALY, H. E. & FARLEY, J. (2003) **Ecological Economics: principles and applications.** Washington, U.S.A: Island Press, 2004.

DAVIS, L.E. & NORTH, D. C. (2008 [1971]) **Institutional Change and American Economic Growth**. Cambridge: Cambridge University Press, 1971.

DENICH, M. (1991) **Estudos da Importância de uma Vegetação Secundária Nova para o Incremento da Produtividade do Sistema de Produção na Amazônia Oriental Brasileira.** Instituto de Agricultura e Higiene Animal nos Trópicos e Subtrópicos. Universidade Georg August de Göttingen. Tese de Doutorado. República Federal da Alemanha. Eschborn. 1991. 284p [tradução em Português].

DENICH, M., VIELHAUER, K., KATO, M.S.A. BLOCK, A. KATO, O.R., SÁ, T.D.A., LÜCKE, W., VLEK, P.L.G. (2004) Mechanized land preparation in forest-based fallow systems: The experience from Eastern Amazonia. Agroforestry Systems 61: 91–106, 2004.

DENICH, M., VLEK, P.L.G., SÁ, T.D.A., VIELHAUER,K., LÜCKE, W. (2005) A concept for the development of fire-free fallow management in the Eastern Amazon, Brazil. **Agriculture, Ecosystems and Environment** 110 (2005) 43–58.

DIXIT, A. K., AND J. E. STIGLITZ (1977): Monopolistic Competition and Optimum Product Diversity," **American Economic Review**, 67(3), 297-308.

DRUKKER, D.M., PRUCHA, I.,R., RACIBORSKI, R. A command for estimating spatial-autoregressive models with spatial-autoregressive disturbances and additional endogenous variables. **The Stata Journal** (2011) 1, Number 1, pp. 1–13.

DUFLO, E., KREMER, M., ROBINSON, J. (2008) How High Are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya.**American Economic Review**, Vol. 98, No. 2, Papers and Proceedings of the OneHundred Twentieth Annual Meeting of the American Economic Association.

FAMINOW, M. (1997) Spatial Economics of Local Demand for Cattle Products in Amazon Development. **Agriculture, Ecosystems & Environment**. Volume 62, Issue 1, March 1997, Pages 1–11

FAMINOW, M. D., BENSON, B. L. (1990) Integration of Spatial Markets. **American Journal of Agricultural Economics**, Vol. 72, No. 1 (Feb., 1990), pp. 49-62

FEARNSIDE (1990) Fire in the Tropical Rain Forest of the Amazon Basin In Goldammer (1990) (Ed.) **Fire in the tropical biota: ecosystem processes and global challenges.** London, UK: Springer-Verlag.

FERES, J., REIS, E. J., SPERANZA, J. S. (2009) **Mudanças climáticas globais e seus impactos sobre os padrões de uso do solo no Brasil.** SOBER 2009 (congress paper).

FIRGO, M. (2012) **Centrality and Pricing in Spatially Differentiated Markets.** Doctoral thesis, WU Vienna University of Economics and Business. Available at:http://epub.wu.ac.at/3461/

GÁMEZ MARTÍNEZ, M., LORENZO, J. M. M., RUBIO, N.G. (2000) Kriging methodology for regional economic analysis: estimating the housing price in Albacete. **IAER**: AUGUST 2000, VOL. 6, NO. 3

GARDNER, T. (2012) Coordinator of Projeto Amazônia Sustentavel (RAS) and Researcher at Cambridge University (UK, Zoology department)

GARDNER, T. AND 80 CO-AUTHORS (2013) A social and ecological assessment of tropical land-uses at multiple scales: the Sustainable Amazon Network. **Philosophical Transactions of the Royal Society.** http://rstb.royalsocietypublishing.org/content/368/1619/20120166.full.pdf?keytype=ref&ijkey=YFq0E8KCVQafJ8N

GERWING, J. J. (2002) Degradation of forests through logging and fire in the eastern Brazilian Amazon. **Forest Ecology and Management** 157 (2002) 131–141.

GOODWIN, B. K., SCHROEDER, T. C. (1991) Cointegration Tests and Spatial Price Linkages in Regional Cattle Markets. **American Journal of Agricultural Economics**, Vol. 73, No. 2 (May, 1991), pp. 452-464

GUIMARÃES, J., VERÍSSIMO, A., AMARAL, P., DEMACHKI, A. (2011) **Municípios verdes: caminhos para a sustentabilidade.**Instituto do Homem e Meio Ambiente da Amazônia (Imazon).http://www.imazon.org.br/publicacoes/livros/municipios-verdes-caminhos-para-a-sustentabilidade

HÖLSCHER, D., SÁ, MÖLLLER, R. F., DENICH, M., FÖLSTER, H. (1997) Nutrient input-output budget of shifting agriculture in Eastern Amazonia. **Nutrient Cycling in Agroecosystems** 47: 49-57, 1997.

IBAMA (1998) **Portaria Nº 94-N, DE 9 de Julho DE 1998**. Establishes the mandatory requirement of controlled burning permits for all purposeful fire utilization, for all Brazilian territory.

IBGE (2009) Municipal Crop Production of 2009. Municipality level data. Online Data. http://www.sidra.ibge.gov.br/

IBGE (2010) Brazilian Agricultural Census of 2006. Municipality level data. CD-ROM.

IBGE (2013) Municipal Crop Production. Municipality level data. Online Data. http://www.sidra.ibge.gov.br/

INPE (2013) Fire detections database of the Brazilian National Institute for Space Research. http://www.dpi.inpe.br/proarco/bdqueimadas/

ISCDE (1997) International Standard Classification of Education. Available at http://www.unesco.org/education/information/nfsunesco/doc/isced_1997.htm

JUST, R. E., ZILBERMAN, D., HOCHMAN, E. (1983) Estimation of Multicrop Production Functions. **American Journal of Agricultural Economics**, Vol. 65, No. 4 (Nov., 1983), pp. 770-780

KATO, O.R. (1998a) **Fire-free land preparation as an alternative to slash-and-burn agriculture in the Bragantina region, eastern Amazon:** crop performance and nitrogen dynamics. Tese de Doutorado, Göttingen, Novembro de 1998.

KATO, M.S.A (1998b) **Fire-free land preparation as an alternative to slash-and-burn agriculture in the Bragantina region, eastern Amazon:** crop performance and phosphorous dynamics. Tese de Doutorado, Göttingen, Novembro de 1998.

KATO, M.S.A., KATO, O.R., DENICH, M., VLEK, P.L.G (1999) Fire-free alternatives to slash-and-burn for shifting cultivation in the eastern Amazon region: the role of fertilizers. **Field Crops Research** 62 (1999) 225-237.

KELEJIAN, H. H., PRUCHA, I. R. (2010) Specification and estimation of spatial autoregressive models with autoregressive and heteroskedastic disturbances. **Journal of econometrics.** Volume 157, Issue 1, July 2010, Pages 53–67.

KEREKES, C. B., WILLIAMSON, C. R. (2008) Unveiling de Soto's mystery: property rights, capital formation, and development. **Journal of Institutional Economics** (2008), 4: 3, 299–325

KLEMICK, H.(2011) Shifting cultivation, forest fallow,and externalities in ecosystem services: Evidence from the Eastern Amazon. **Journal of Environmental Economics and Management** 61(2011)95–106.

KNAPP, K. C. (1987) Dynamic Equilibrium in Markets for Perennial Crops.**American Journal of Agricultural Economics**, Vol. 69, No. 1 (Feb., 1987), pp. 97-105.

KUNTZ, R. (1982) **Capitalismo e natureza: ensaio sobre os fundadores da economia política**. São Paulo: Brasiliense.

LANZER, E.A. & PARIS, Q. (1981) A New Analytical Framework for the Fertilization Problem. **American Journal of Agricultural Economics**, Vol. 63, No. 1 (Feb., 1981), pp. 93-103.

LAU, L. J. (1976) A characterization of the normalized restricted profit function. **Journal of economic theory** 12, 131-163.

LIEBOWITZ, S. J., MARGOLIS, S. E. (2000) "Path dependence" In Bouckaert, Boudewijn and De Geest, Gerrit (eds.), **Encyclopedia of Law and Economics, Volume I.** The History and Methodology of Law and Economics, Cheltenham, Edward Elgar, 2000, 1094 p. ISBN 1 85898 984 1

LIVERMAN, D., MORAN, E.F., RINDFUSS, R.R E STERN, P.C. (1998) **People and pixels: linking remote sensing and social science.** National Academy Press, Washington, D.C.

LOPES, B. M. (2006). **Uso da capoeira na extração de lenha: em três comunidades locais no pólo Rio Capim do PROAMBIENTE-PA**. PhD dissertation, Federal University of the Para State, Brazil. http://repositorio.ufpa.br/jspui/handle/2011/1709

MAPA (2013) Sanitary norms for slaughterhouses. Ministry of Agriculture. Available at/ http://www.agricultura.gov.br/animal/exportacao/requisitos-sanitarios

MARGULIS, S. (2003). Causes of deforestation in the Brazilian Amazon, **World Bank Working Paper Series.** Washington, DC: World Bank.

MARTINS, H. & SOUZA JR, C. (2011) Avaliação do Desmatamento e do Cadastro Ambiental Rural (CAR) no Pará: bases para o Programa Municípios Verdes. IMAZON. O Estado da Amazônia n° 21.

MAS-COLLEL, A.,WHINSTON, M. D., GREEN, J. D. (1995) **Microeconomic Theory**. New York: Oxford University Press.

MATOS, M. M., & UHL, C. (1994) Economic and Ecological Perspectives on Ranching in the Eastern Amazon. **World Development**, Vol. 22, No. 2, pp. 145-158, 1994.

MAXWELL, S. (1986). The role of case studies in farming systems research. **Agricultural Administration** 21 (1986), 147-180.

MAZOYER, M. & ROUDART, L. (2009). **História das agriculturas no mundo: do neolítico à crise contemporânea.** São Paulo: Editora UNESP; Brasília, DF: NEAD.

MCT (2010) Brazilian Inventory of Anthropogenic Emissions by Sources and Removals by Sinks of Greenhouse Gases not Controlled by the Montreal Protocol, second comunication, part 2.

MENDONÇA, M. J. C., M. D. V. DIAZ, D. NEPSTAD, R. S. DA MOTTA, A. ALENCAR, J. C. GOMES, AND R. A. ORTIZ. (2004). The economic cost of the use of fire in the Amazon. **Ecological Economics** 49:89-105.

MERTENS, B., POCCARD-CHAPUIS, R., PIKETTY, M. G., LACQUES, A. E., VENTURIERI, A. (2002) Crossing spatial analyses and livestock economics to understand deforestation processes in the Brazilian Amazon: the case of São Félix do Xingú in South Pará. **Agricultural Economics** 27 (2002) 269–294.

MERTZ,O., WADLEY,R.L., NIELSEN, U., BRUUN, T.B., COLFER, C.J.P., NEERGAARD, A., JEPSE, M.R., MARTINUSSEN, T., ZHAO, Q., NOWEG,G. T., MAGID,J. (2008) A fresh look at shifting cultivation: Fallow length an uncertain indicator of productivity. **Agricultural Systems** 96 (2008) 75–84.

METZGER, J. P.(2002) Landscape dynamics and equilibrium in areas of slash-and-burn agriculture with short and long fallow period (Bragantina region, NE Brazilian Amazon) **Landscape Ecology** 17: 419–431, 2002.

MOFFITT, R. (2001). Policy interventions, low-level equilibria, and social interactions. In: Durlauf, S., Young, P. (Eds.), Social Dynamics. Brookings Institution Press and MIT Press, pp. 45–82.

MOORE, M. R., NEGRI, D. H. (1992) A multicrop production model of irrigated agriculture, applied to water allocation policy of the Bureau of Reclamation.**Journal of Agricultural and Resource Economics**, 17(1): 29-43

MT (2013) Webpage of the Brazilian Ministry of Transport. “2.2.2. Sistema viário”. http://www.transportes.gov.br/index/conteudo/id/36604

NEIDEMEIER, F. R. (2011) Projeto «Município Verde» Paragominas. The Nature Conservancy. Presentation. http://www.sema.pa.gov.br/semana_meio_ambiente/apresentacoes/07.06.11/10h40_mauro_lucio.pdf

NELSON, G., GEOGHEGAN, J., (2002). Modeling Deforestation and Land Use Change: Sparse Data Environments. **Agricultural Economics** 27(3):201-216.

NEPSTAD, D., MOREIRA, A.G., ALENCAR, A. A. (1999a). **Flames in the rainforest: origins, impacts and alternatives to amazonian fire.** The Pilot Program to Conserve the Brazilian Rain Forest, Brasilia, Brazil.

NEPSTAD, D. C., A. VERISSIMO, A. ALENCAR, C. NOBRE, E. LIMA, P. LEFEBVRE, P. SCHLESINGER, C. POTTER, P. MOUTINHO, E. MENDOZA, M. COCHRANE, AND V. BROOKS. (1999b). Large-scale impoverishment of Amazonian forests by logging and fire. **Nature** 398:505-508.

NEPSTAD, D., CARVALHO; G. BARROS, C.(2001) Road paving, fire regime feedbacks, and the future of Amazon Forest. **Forest Ecology and Management** 154 (2001) 396-407.

NEPSTAD, D., G. CARVALHO, A. C. BARROS, A. ALENCAR, J. P. CAPOBIANCO, J. BISHOP, P. MOUTINHO, P. LEFEBVRE, U. L. SILVA, AND E. PRINS (2001). Road paving, fire regime feedbacks, and the future of Amazon forests. **Forest Ecology and Management** 154:395-407.

NEPSTAD, D.C., STICKLER, C. M., ALMEIDA, O. T. (2006) Globalization of the amazon soy and beef industry: opportunities for conservation.**Conservation Biology.** 2006 Dec;20(6):1595-603.

NEWEY, W. K. (1987) Efficient estimation of limited dependent variable models with endogenous explanatory variables. **Journal of Econometrics** 36: 231-250.

NICHOLSON, W. (2002) Microeconomic Theory Basic Principles and Extensions.8th edition. [Cincinnata, Ohio] : South-Western/Thomson Learning, c2002.

OECD (2011) Education at a Glance 2011.Country note – Brazil. Available at http://www.oecd.org/brazil/48657313.pdf

PACHECO, P. (2012) Actor and frontier types in the Brazilian Amazon: Assessing interactions and outcomes associated with frontier expansion. **Geoforum** 43 (2012) 864–874.

PALM, C.A.; VOSTI, S.A.; SANCHEZ, P.A.; ERICKSEN, P.J. (eds.) (2004) **Slash-and-Burn Agriculture: the search for alternatives.** New York: Columbia University, 2004.Tomich et al: 1998

PARMAN, J. (2012) Good schools make good neighbors: Human capital spillovers in early 20th century agriculture. **Explorations in Economic History** 49 (2012) 316–334

PARRY, L. (2012) Coordinator of Projeto Amazônia Sustentavel (RAS) socioeconomic surveys (Paragominas municipality was covered in 2011) and Lecturer at the Lancaster Environment Centre.

PERZ, S. G., WALKER, R. T. (2002) Household Life Cycles and Secondary Forest Cover Among Small Farm Colonists in the Amazon.**World Development** Vol. 30, No. 6, pp. 1009–1027, 2002

PFAFF, A. (1999). "What Drives Deforestation in the Brazilian Amazon? Evidence from satellite and socioeconomic data". J. **Environ. Econ. Manage.** 37, 26.

PFAFF, A. ROBALINO, J. A., WALKER, R., REIS, E. J. PERZ, S. BOHRER, C. B., ALDRICH, S. (2005) Road Investments, Spatial Intensification and Deforestation in the Brazilian Amazon http://nemesis.org.br/sec-din5.php?id=0000000118&i=pt

PFFAF, A. & WALKER, R. (2010) Regional interdependence and forest "transitions": Substitute deforestation limits the relevance of local reversals. **Land Use Policy** 27 (2010) 119–129.

PINTO, A., AMARAL, P., SOUZA JR., C., VERÍSSIMO, A., SALOMÃO, R., GOMES, G., & BALIEIRO, C. (2009). Diagnóstico Socioeconômico e Florestal do município de Paragominas (p. 65). Belém: Imazon.

POLLINI, J. (2009) Agroforestry and the search for alternatives to slash-and-burn cultivation: From technological optimism to a political economy of deforestation. **Agriculture, Ecosystems and Environment** 133 (2009) 48–60.

QUINTIERE, J. G. (2006) **Fundamentals of fire phenomena**. John Wiley & Sons, England.

REYNAL, V.; MUCHAGATA, A. G., TOPALL, O.; HÉBETTE, J. (1996) **Agriculturas familiares e desenvolvimento em frente pioneira amazônica**. Belém: LASAT/CAT.

RICHARDS, P. D., MYERS, R. J., SWINTON, S., WALKER, R. T. (2012) Exchange rates, soybean supply response, and deforestation in South America.**Global Environmental Change** 22 (2012) 454–462

RIGHI, C. A.; LIMA, GRAÇA, P.M.L.A., C., C. C.; FEIGL, B. J., FEARNSIDE, P. M. (2009) Biomass burning in Brazil's Amazonian ''arc of deforestation'': Burning efficiency and charcoal formation in a fire after mechanized clearing at Feliz Natal, Mato Grosso. **Forest Ecology and Management** 258 (2009) 2535–2546.

ROBALINO, J.A., & PFFAF, A (2011) Contagious development: Neighbor interactions in deforestation. Journal of Development Economics. **Journal of Development Economics**, Volume 97, Issue 2, March 2012, Pages 427-436

ROCHA, K., MOREIRA, A. R. B., REIS, E. J., CARVALHO, L. (2006) The market value of forest concessions in the Brazilian Amazon: a Real Option approach. **Forest Policy and Economics** 8 (2006) 149– 160.

ROTHERMEL, R. C. (1972) A mathematical model for predicting fire spread in wildland fuels.**United States Department of Agriculture (USDA)**, Forest Service. Research Paper INT-115.http://www.fs.fed.us/rm/pubs_int/int_rp115.pdf

SCATENA, F. N.; WALKER, R. T.; HOMMA, A. K. O.; DE CONTO, A. J.; FERREIRA, C. A. P.; CARVALHO, R. A.; ROCHA, A. C. P. N.; SANTOS, A. I. M., AND OLIVEIRA, P.M. (1996). Cropping and fallowing sequences of small farms in the "terra firme" landscape of the Brazilian Amazon: a case study from Santarém, Pará. **Ecological Economics**. 18(1) :29-40.

SCHELLING, T. (1973) Hockey Helmets, Concealed Weapons, and Daylight Saving: A Study of Binary Choices with Externalities.**The Journal of Conflict Resolution**, Vol. 17, No. 3 (Sep., 1973), pp. 381-428.

SCHUCK, E.C., NGANJE, W., YANTIO, D. (2002) The role of land tenure and extension education in the adoption of slash and burn agriculture. **Ecological Economics**. Volume 43, Issue 1, November 2002, Pages 61–70

SCHULTZ, T. W. (1975) The Value of the Ability to Deal with Disequilibria. **Journal of Economic Literature**, Vol. 13, No. 3 (Sep., 1975), pp. 827-846

SCOTT, J. H. & BURGAN, R. E (2005) Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. **United States Department of Agriculture (USDA), Forest Service**. General Technical Report RMRS-GTR-153.http://www.fs.fed.us/rm/pubs/rmrs_gtr153.pdf

SHAFRAN, A. P. (2008) Risk externalities and the problem of wildfire risk. **Journal of Urban Economics** 64 (2008) 488–495.

SHIMABUKURO, Y. E., V. DUARTE, E. ARAI, R. M. FREITAS, A. LIMA, D. M. VALERIANO, I. F. BROWN, AND M. L. R. MALDONADO.(2009). Fraction images derived from Terra Modis data for mapping burnt areas in Brazilian Amazonia. **International Journal of Remote Sensing** 30:1537–1546.

SHUMWAY, C. R. (1983) Supply, Demand, and Technology in a Multiproduct Industry: Texas Field Crops. **American Journal of Agricultural Economics**, Vol. 65, No. 4 (Nov., 1983), pp. 748-760.

SIMLAM (2012) Rural environmental registry database (CAR). Confidential information compiled and stored in Para State Environmental Agency computers. Accessed through Rede Amazônia Sustentável (RAS) with support from The Nature Conservancy unit at Paragominas municipality. Version updated to April 2012.

SIMMONS, C. S., R. T. WALKER, C. H. WOOD, E. ARIMA, AND M. COCHRANE. (2004). Wildfires in Amazonia: a pilot study examining the role of farming systems, social capital, and fire contagion. **Journal of Latin American Geography** 3:81-95.

SIMON, C. P. & BLUME, L. E. (1994) **Mathematics for Economists**. New York: W.W. Norton & Company.

SMERALDI, R., MAY, P. (2008) O reino do gado. Uma nova fase na pecuarização da Amazônia Brasileira. Amigos da Terra (NGO). Available at: http://www.agropecuaria.org/agropecuaria/GanaderiaAmazonia.pdf

SOMMER, R., VLEK, P. L. G., SÁ, T.A.D., VIELHAUER, K., COELHO, R. F. R., FÖLSTER, H. (2004) Nutrient balance of shifting cultivation by burning or mulching in the Eastern Amazon – evidence for subsoil nutrient accumulation. **Nutrient cycling in agroecosystems** Volume 68, Number 3 (2004), 257-271.

SORRENSEN, C. (2004) Contributions of fire use study to land use/cover change frameworks: understanding landscape change in agricultural frontiers. **Human Ecology** 32:395-419.

SORRENSEN, C. (2000). Linking smallholder land use and fire activity: examining biomass burning in the Brazilian Lower Amazon. **Forest Ecology and Management** 128:11-25.

SORRENSEN, C. (2009). Potential hazards of land policy: conservation, rural development and fire use in the Brazilian Amazon. **Land Use Policy** 26:782-791.

SOUZA, M. L.L. (2009) **Institutional arrangements for fire management in the Brazilian Amazon**. Master dissertation, University of Florida, U.S.A. http://etd.fcla.edu/UF/UFE0024926/souza_m.pdf

TCU (2000) Sistema Nacional de Prevenção e Combate aos Incêndios Florestais (IBAMA-MMA): **relatório de auditoria**. Tribunal de Contas da União, Brasília, DF. http://portal2.tcu.gov.br/portal/page/portal/TCU/comunidades/programas_governo/areas_atuacao/meio_ambiente/Relat%C3%B3rio%20de%20auditoria%20prevfogo.pdf

TERRACLASS (2011) Land use map for Brazilian Amazon, reference year: 2008. National Institute for Space Research (INPE), **Terra Class project** http://www.inpe.br/cra/projetos_pesquisas/terraclass.php

TERRACLASS (2013) Land use map for Brazilian Amazon, reference year: 2010. National Institute for Space Research (INPE), **Terra Class project** http://www.inpe.br/cra/projetos_pesquisas/terraclass.php

THIELE, G. (1992), The Dynamics of Farm Development in the Amazon: The Barbecho Crisis Model. **Agricultural Systems** 42 (1993) 179-197.

TOMICH, T.P., VAN NOODWIJK, M., VOSTI, S.A., WITCOVER, J. (1998) Agricultural development with rainforest conservation: methods for seeking best bet alternatives to slash-and-burn, with applications to Brazil and Indonesia. **Agricultural Economics** 19 (1998) 159-174.

VALE (2011). Vale Florestar. Reforestation of degraded tropical land in Brazilian Amazon.Project Design Document (PDD). UNFCCC. Available at: http://cdm.unfccc.int/UserManagement/FileStorage/0VBFQWCXGI5L6AKHMJP4O9Y8NT31ZU

VARIAN, H. (1992) **Microeconomic Analysis**, third edition. New York: W.W. Norton & Company.

VERISSIMO, A., BARRETO, P., MATTOS, M., TARIFA, R., UHL, C. (1992) Logging impacts and prospects for sustainable forest management in an old Amazonian frontier: the case of Paragominas. **Forest Ecology and Management**, 55 (1992) 169-199.

VIANA, C., COUDEL, E., BARLOW, J., FERREIRA, J., GARDNER, T., PARRY, L. (2012) **From red to Green: achieving an environmental pact at the municipal level in Paragominas** (Pará, Brazilian Amazon). Working paper presented at the International Society for Ecological Economics Conference, 17 June 2012.

VOSTI, S. A., WITCOVER, J. (1996) Slash-and-burn agriculture – household perspectives. Agriculture, **Ecosystems and Environment** 58 (1996) 23-38.

VOSTI, S.A., WITCOVER, J., CARPENTIER, C. L. (2002) Agricultural Intensification by Smallholders in the Western Brazilian Amazon: from Deforestation to Sustainable Land Use. **International Food Policy Research Institute**, Washington, D.C. Research Report # 130.

WACKERNAGEL, H. (1995) **Multivariate geostatistics an introduction with applications**. Berlin Springer : 1995.

WAICHMAN, A. V., EVE, E., NINA, N.C.S. (2007) Do farmers understand the information displayed on pesticide product labels? A key question to reduce pesticides exposure and risk of poisoning in the Brazilian Amazon. **Crop Protection** 26 (2007) 576–583

WALKER, R., BROWDER, J., ARIMA, E., SIMMONS, C., PEREIRA, R., CALDAS, M., SHIROTA, R., DE ZEN, S. (2009).Ranching and the new global range: Amazônia in the 21st century.**Geoforum** 40 (2009) 732–745

WILSON, J. D.(2012) resource securitypolicies and the restructuring of theAsia-Pacific iron ore market.**Resources Policy** 37 (2012) 331–339

WILLIAMSON, O. (1996) **The Mechanisms of Governance**. New York: Oxford University Press.

WOOLDRIDGE, J. M. (2002) **Econometric analysis of cross section and panel data**. The MIT Press Cambridge, Massachusetts, London, England.

ZELLNER, A. (1963). Estimators for seemingly unrelated regression equations: Some exact finite sample results. **Journal of the American Statistical Association** 58: 977-992

APPENDICES

APPENDICES: LIST OF TABLES

APPENDIX A.2.1 SECOND ORDER CONDITIONS, CHAPTER 2

A sufficient condition for the equilibrium obtained from the first order conditions to be a global maximum is that the matrix of second derivatives, or Hessian matrix, of the function π(γ, q, z), be negative semidefinite (Mas-Collel et al 1995, appendices and MC MJ, Chiang & Wainwright: 2002, p.316-317, Simon & Blume: 1994, Theorem 17.8, p.403, Varian: 1994, chapter 2, p .28). What is equivalent to the requirement that the function π (γ, q, z) be concave. This last condition is ensured, according to the theorem 16.2 of Simon & Blume (1994) if and only if all seven following conditions are satisfied.

(a) $\frac{\partial^2 \pi}{\partial \gamma^2} \leq 0$

(b) $\frac{\partial^2 \pi}{\partial q^2} \leq 0$

(c) $\frac{\partial^2 \pi}{\partial z^2} \leq 0$

$$(d)\begin{vmatrix} \frac{\partial^2 \pi}{\partial q^2} & \frac{\partial^2 \pi}{\partial q \partial z} \\ \frac{\partial^2 \pi}{\partial q \partial z} & \frac{\partial^2 \pi}{\partial z^2} \end{vmatrix} \geq 0$$

$$(e)\begin{vmatrix} \frac{\partial^2 \pi}{\partial \gamma^2} & \frac{\partial^2 \pi}{\partial z \partial \gamma} \\ \frac{\partial^2 \pi}{\partial z \partial \gamma} & \frac{\partial^2 \pi}{\partial z^2} \end{vmatrix} \geq 0$$

$$(f)\begin{vmatrix} \frac{\partial^2 \pi}{\partial \gamma^2} & \frac{\partial^2 \pi}{\partial q \partial \gamma} \\ \frac{\partial^2 \pi}{\partial q \partial \gamma} & \frac{\partial^2 \pi}{\partial q^2} \end{vmatrix} \geq 0$$

$$(g)\begin{bmatrix} \frac{\partial^2 \pi}{\partial \gamma^2} & \frac{\partial^2 \pi}{\partial q \partial \gamma} & \frac{\partial^2 \pi}{\partial z \partial \gamma} \\ \frac{\partial^2 \pi}{\partial q \partial \gamma} & \frac{\partial^2 \pi}{\partial q^2} & \frac{\partial^2 \pi}{\partial q \partial z} \\ \frac{\partial^2 \pi}{\partial z \partial \gamma} & \frac{\partial^2 \pi}{\partial q \partial z} & \frac{\partial^2 \pi}{\partial z^2} \end{bmatrix} \leq 0$$

Conditions (d) to (g) refer to the determinants of the second and third order principal minors of the hessian matrix. By calculating the derivatives and collecting common terms, one ends with the formulas below.

$$(a)\frac{\partial^2 \pi}{\partial \gamma^2} = w\left(2\frac{\partial s}{\partial \gamma} + \frac{\partial^2 s}{\partial \gamma^2}\gamma\right) + \gamma\frac{\partial^2 f}{\partial x^2}\left(\frac{\partial s}{\partial \gamma}\right)^2$$

$$(b)\ \frac{\partial^2 \pi}{\partial q^2} = \gamma \frac{\partial^2 f}{\partial x^2}$$

$$(c)\ \frac{\partial^2 \pi}{\partial z^2} = \gamma \frac{\partial^2 f}{\partial z^2}$$

$$(d)\ \begin{vmatrix} \frac{\partial^2 \pi}{\partial q^2} & \frac{\partial^2 \pi}{\partial q \partial z} \\ \frac{\partial^2 \pi}{\partial q \partial z} & \frac{\partial^2 \pi}{\partial z^2} \end{vmatrix} = \gamma^2 \left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2} - \left(\frac{\partial^2 f}{\partial x \partial z}\right)^2\right]$$

$$(e)\ \begin{vmatrix} \frac{\partial^2 \pi}{\partial \gamma^2} & \frac{\partial^2 \pi}{\partial z \partial \gamma} \\ \frac{\partial^2 \pi}{\partial z \partial \gamma} & \frac{\partial^2 \pi}{\partial z^2} \end{vmatrix} = \left\{ w\gamma \frac{\partial^2 f}{\partial z^2}\left(2\frac{\partial s}{\partial \gamma} + \frac{\partial^2 s}{\partial \gamma^2}\gamma\right) + \gamma^2 \left(\frac{\partial s}{\partial \gamma}\right)^2 \left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2} - \left(\frac{\partial^2 f}{\partial x \partial z}\right)^2\right]\right\}$$

$$(f)\ \begin{vmatrix} \frac{\partial^2 \pi}{\partial \gamma^2} & \frac{\partial^2 \pi}{\partial q \partial \gamma} \\ \frac{\partial^2 \pi}{\partial q \partial \gamma} & \frac{\partial^2 \pi}{\partial q^2} \end{vmatrix} = \left[w\gamma \frac{\partial^2 f}{\partial x^2}\left(2\frac{\partial s}{\partial \gamma} + \frac{\partial^2 s}{\partial \gamma^2}\right)\gamma\right]$$

$$(g)\ \begin{bmatrix} \frac{\partial^2 \pi}{\partial \gamma^2} & \frac{\partial^2 \pi}{\partial q \partial \gamma} & \frac{\partial^2 \pi}{\partial z \partial \gamma} \\ \frac{\partial^2 \pi}{\partial q \partial \gamma} & \frac{\partial^2 \pi}{\partial q^2} & \frac{\partial^2 \pi}{\partial q \partial z} \\ \frac{\partial^2 \pi}{\partial z \partial \gamma} & \frac{\partial^2 \pi}{\partial q \partial z} & \frac{\partial^2 \pi}{\partial z^2} \end{bmatrix} = \gamma^2 \left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2} - \left(\frac{\partial^2 f}{\partial x \partial z}\right)^2\right]\left[w\left(2\frac{\partial s}{\partial \gamma} + \frac{\partial^2 s}{\partial \gamma^2}\gamma\right)\right]$$

Given the recurrence of certain expressions, it is possible, by inspection, to reduce the seven conditions listed in the previous step to the following five conditions:

$$(\mathrm{SOC1})\ \frac{\partial^2 f}{\partial x^2} \leq 0$$

$$(\mathrm{SOC2})\ \frac{\partial^2 f}{\partial z^2} \leq 0$$

$$(\mathrm{SOC3})\ \frac{\partial s}{\partial \gamma} \leq 0$$

$$(\mathrm{SOC4})\ \frac{\partial^2 s}{\partial \gamma^2} \leq 0$$

$$(\mathrm{SOC5})\ \frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2} \geq \left(\frac{\partial^2 f}{\partial x \partial z}\right)^2$$

The principle of diminishing marginal returns, applied to factors and nutrients, ensures that SOC1 and SOC2 are met. Now, to ensure validity of SOC3 and SOC4, it is necessary that both the first and second partial derivatives of s(γ, Ω) in respect to γ be negative. It suffices to assume that the growth of secondary vegetation can be represented by a logistic function, and, thus, u '(.)> 0 and u '(.)< 0, a standard assumption of models of optimal rotation for tree stands (Amacher et al: 2009, p.78).

(SOC3) From u '(.)> 0, where u (F) is the function that governs the growth of secondary vegetation (as acknowledged in the text), one has:

$$\frac{\partial s(\gamma,\Omega)}{\partial\gamma} = \frac{\partial}{\partial\gamma}(u(F)\psi\lambda) = \frac{\partial}{\partial\gamma}\{u[(1-\gamma)T]\psi\lambda\} = \frac{\partial}{\partial\gamma}\{u[(1-\gamma)T]\psi\lambda\} = -T\psi\lambda\frac{\partial u}{\partial F}$$

$$\rightarrow S\left[\frac{\partial s(\gamma,\Omega)}{\partial\gamma}\right] = (-1)S\left[\frac{\partial u}{\partial F}\right] = (-1)$$

(SOC4) The hypothesis that u’’(.) < 0 leads to:

$$\frac{\partial^2 s(\gamma,\Omega)}{\partial\gamma^2} = -T\psi\lambda\frac{\partial}{\partial\gamma}\left(\frac{\partial u}{\partial F}\right) = -T\psi\lambda\frac{\partial^2 u}{\partial F^2}(-T) = T^2\psi\lambda\frac{\partial^2 u}{\partial F^2} \rightarrow S\left[\frac{\partial^2 s(\gamma,\Omega)}{\partial\gamma^2}\right] = S\left[\frac{\partial^2 u}{\partial F^2}\right]$$
$$= (-1)$$

The SOC5 has no clear interpretation is only one criterion that requires concavity of the production function in the neighborhood of the equilibrium (Nicholson: 2002, p. 51).

For production functions with diminishing returns that attend the condition SOC5, the equilibrium is a global maximum. It is assumed that the function f(x, z) fulfills both requirements.

A finding that worth to be mentioned is that if SOC1-SOC5 are strictly valid, the equilibrium is both a global and local maximum (Simon & Blume: 1994, Theorems 17.3, p.399 and 17.8, p.403).

APPENDIX A.2.2 EQUILIBRIUM CONDITION AND HOMOGENEITY OF DEGREE ONE, CHAPTER 2

A.2.2.1 Main demonstrations

Homogeneity of degree makes possible to reformulate the equilibrium condition in a more enlightening form.

(i) (FOC 1) $\hat{\pi} = -\gamma \frac{\partial f}{\partial x} \frac{\partial s}{\partial \gamma}$

(ii) (FOC 2) $\frac{\partial f}{\partial x} = w$

(iii) Taking (ii) into (i): $\hat{\pi} = -\gamma w \frac{\partial s}{\partial \gamma}$

(iv.a) Being λ a positive scalar, $f(\lambda x, \lambda z) = \lambda \hat{y}$, because, if F(X,Z) is homogeneous of degree one, $f(x,z) = F(X,Z)\ \gamma^{-1}$ is also homogeneous of degree one. This is demonstrated in the section B.2 bellow. Additionally, $\hat{y}$ is such that $y = \gamma \hat{y}$.

(iv.b) Following the standard demonstration of Euler's formula (Mas-Collel et al: 1995, teorema M.B.2, p.929), both sides of the equation (iv.a) are derived in λ, to get $\frac{\partial f}{\partial f_1} x + \frac{\partial f}{\partial f_2} z = \hat{y}$, where $f_1 = \lambda x$ e $f_2 = \lambda z$. Now, as generally, it is assumed that $\lambda = 1$, in order to have $f_1 = x$ and $f_2 = z$ and, by consequence, $\hat{y} = \frac{\partial f}{\partial x} x + \frac{\partial f}{\partial z} z$.

(iv.c) In equilibrium, $\frac{\partial f}{\partial x} = w$ e $\frac{\partial f}{\partial z} = c$, according to FOCs 2 and 3.

(iv.d) Combining (iv.b) and (iv.c): $\hat{y}^* = wx^* + cz^*$. In what follows, the asterisks are omitted but, nevertheless, all variables take their equilibrium levels.

(iv.e) In equilibrium, $x = s(\gamma,\Omega) + q$. Taking this to (iv.d) one has: $\hat{y} = wq + ws(\gamma,\Omega) + cz$.

(v.a) $\pi = \gamma[f(x,z) - cz - wq] = \gamma[\hat{y} - cz - wq]$. Incorporating (iv.e): $\pi = \gamma[wq + ws(\gamma,\Omega) + cz - cz - wq] \rightarrow \pi = \gamma w s(\gamma,\Omega)$.

(v.b) $\pi = \gamma \hat{\pi} \rightarrow \hat{\pi} = \frac{\pi}{\gamma}$

(v.c) Combining the result of (v.a) with the sentence (v.b):

$$\hat{\pi} = ws(\gamma,\Omega)$$

(v.d) The total profit generated by SB&A is given by $R = \pi A_0$ and the total amount of nutrients incorporated to the soil form secondary vegetation conversion is given by $S = s(\gamma,\Omega)A_c$. Gathering this two conditions and as well (v.c):

$$\frac{\pi}{\gamma} = ws(\gamma,\Omega) \rightarrow \frac{R}{A} = ws(\gamma,\Omega)\gamma \rightarrow R = ws(\gamma,\Omega)A_C \rightarrow R = wS$$

(vi) The two equilibrium conditions, (iii) and (v.c), have to be, mandatorily, equivalent, i.e.:

$$-\gamma w\frac{\partial s}{\partial \gamma} = ws(\gamma,\Omega) \rightarrow -\gamma\frac{\partial s}{\partial \gamma} = s(\gamma,\Omega) \rightarrow \frac{\gamma}{s(\gamma,\Omega)}\frac{\partial s}{\partial \gamma} = -1$$

The last step contains a right hand side expression which is clearly an elasticity. More precisely, it is the elasticity of the average amount of cost-free nutrients by hectare, s(.), in respect to the land utilization factor, γ. Consequently:

$$\varepsilon_\gamma^s(\gamma,\Omega) = -1$$

This statement says something about the optimal level of γ: it is reached when the elasticity becomes unitary. It is, however, possible to give a more precise and clarifying interpretation to the result just reached. For this, one extra step is need.

(vii) To assess the condition obtained, it is necessary to know how the elasticity varies with γ. The calculation of the partial derivate yields:

$$\frac{\partial \varepsilon_\gamma^s(\gamma,\Omega)}{\partial \gamma} = \frac{\partial}{\partial \gamma}\left(\frac{\partial s}{\partial \gamma}\frac{\gamma}{s(\gamma,\Omega)}\right) = \frac{\partial^2 s}{\partial \gamma^2}\frac{\gamma}{s(\gamma,\Omega)} + \frac{\partial s}{\partial \gamma}\left(\frac{1}{s(\gamma,\Omega)} - \frac{\gamma}{s(\gamma,\Omega)^2}\frac{\partial s}{\partial \gamma}\right)$$

$$= \frac{\partial^2 s}{\partial \gamma^2}\frac{\gamma}{s(\gamma,\Omega)} + \frac{\partial s}{\partial \gamma}\frac{1}{s(\gamma,\Omega)} - \frac{\gamma}{s(\gamma,\Omega)^2}\left(\frac{\partial s}{\partial \gamma}\right)^2$$

As noted in the appendix A.2.1 (see SOC3 and SOC4), the terms $\frac{\partial^2 s}{\partial \gamma^2}$ e $\frac{\partial s}{\partial \gamma}$ are always negative. What guarantees a negative sign for the partial derivative of the elasticity. That way, its magnitude falls with the rise if γ. Reminding that the elasticity is always negative, on has:

$(vii.a)\varepsilon_\gamma^s(\gamma,\Omega) < \varepsilon_\gamma^s(\gamma^*,\Omega) = -1, se\ \gamma > \gamma^*$

$(vii.b)\varepsilon_\gamma^s(\gamma,\Omega) > \varepsilon_\gamma^s(\gamma^*,\Omega) = -1, se\ \gamma < \gamma^*$

A.2.2.2 Auxiliary demonstration: F(X,Z) is homogeneous of degree one → f(x,z) is homogeneous of degree one

(i) F(X, Z) = $F\left(\frac{X}{AC}\frac{C}{T}, \frac{X}{AC}\frac{C}{T}\right)$= F(xγ, zγ) = γf(x, z) (what is guaranteed by the homogeneity of degree one of F(.)) → F(X, Z) = γf(x, z).

(ii) The homogeneity of degree one of F() ensures other relevant condition, namely: F(λX, λZ) = λF(X, Z), λ being a positive scalar.

(iii) F(λX, λZ) = $F\left(\lambda\frac{X}{AC}\frac{C}{T}, \lambda\frac{z}{AC}\frac{C}{T}\right)$= F(λxγ, λzγ), what is a consequence of the definitions of x, z and γ. Then F(λX, λZ) = F(λxγ, λzγ). Additionally, as was done in (i), one can writes γF(λx, λz) = γf(λx, λz). It results that, thus, F(λX, λZ) = γf(λx, λz).

(iv) Multiplying both of the sides of the condition obtained in (i) by λ, on has that λF(X, Z) = λγf(x, z).

(v) Combining (ii), (iii) e (iv), it finally results that $F(\lambda X, \lambda Z) = \lambda F(X, Z)$ is equivalent to (by (iii) e (iv)) to the sentence $\gamma f(\lambda x, \lambda z) = \lambda\gamma f(x, z)$. Eliminating the factor that is common to both of the terms, γ, it results that $f(\lambda x, \lambda z) = \lambda f(x, z)$, what ends the demonstration.

APPENDIX A.2.3 IMPLICIT FUNCTION THEOREM AND COMPARATIVE STATICS, CHAPTER 2

To know the effect of the parameters on the equilibrium values of the problem variables, the implicit function theorem can be used (Mas-Colell et al: 2005, p.941, theorem M.E.1). It postulates that:

$$D_q\eta(\bar{q}) = -D_xf(\bar{x};\bar{q})^{-1}D_qf(\bar{x};\bar{q})$$

Where $D_q\eta(\bar{q})$ is the matrix of derivatives of the implicit functions in the basis of which the variables can be written as functions of the parameters (only). The implicit functions are, in the case, the FOCs. $D_xf(\bar{x};\bar{q})$ e $D_qf(\bar{x};\bar{q})$ will be calculated in what follows.

A.2.3.1 $\boldsymbol{D_xf(\bar{x};\bar{q})}$ (Inverse of the hessian matrix)

$$D_xf(x;q) = \begin{bmatrix} \frac{\partial f_1}{\partial \gamma} & \frac{\partial f_1}{\partial q} & \frac{\partial f_1}{\partial z} \\ \frac{\partial f_2}{\partial \gamma} & \frac{\partial f_2}{\partial q} & \frac{\partial f_2}{\partial z} \\ \frac{\partial f_3}{\partial \gamma} & \frac{\partial f_3}{\partial q} & \frac{\partial f_3}{\partial z} \end{bmatrix} = \begin{bmatrix} \frac{\partial^2 \pi}{\partial \gamma^2} & \frac{\partial^2 \pi}{\partial q \partial \gamma} & \frac{\partial^2 \pi}{\partial z \partial \gamma} \\ \frac{\partial^2 \pi}{\partial q \partial \gamma} & \frac{\partial^2 \pi}{\partial q^2} & \frac{\partial^2 \pi}{\partial q \partial z} \\ \frac{\partial^2 \pi}{\partial z \partial \gamma} & \frac{\partial^2 \pi}{\partial q \partial z} & \frac{\partial^2 \pi}{\partial z^2} \end{bmatrix} = \begin{bmatrix} A & B & C \\ B & D & E \\ C & E & F \end{bmatrix}$$

The inverse of the schematic matrix is given by:

$$\frac{1}{\Delta}\begin{bmatrix} E^2 - DF & BF - CE & CD - BE \\ BF - CE & C^2 - AF & AE - BC \\ CD - BE & AE - BC & B^2 - AD \end{bmatrix}$$

Where $\Delta = (-ADF + AE^2 + B^2F - 2BCE + C^2D)$

<u>(i) Δ</u>

$\Delta = (-ADF + AE^2 + B^2F - 2BCE + C^2D) =$

$$-\frac{\partial^2\pi}{\partial\gamma^2}\frac{\partial^2\pi}{\partial q^2}\frac{\partial^2\pi}{\partial z^2} + \frac{\partial^2\pi}{\partial\gamma^2}\left(\frac{\partial^2\pi}{\partial q\partial z}\right)^2 + \left(\frac{\partial^2\pi}{\partial q\partial\gamma}\right)^2\frac{\partial^2\pi}{\partial z^2} - 2\frac{\partial^2\pi}{\partial q\partial\gamma}\frac{\partial^2\pi}{\partial z\partial\gamma}\frac{\partial^2\pi}{\partial q\partial z} + \left(\frac{\partial^2\pi}{\partial z\partial\gamma}\right)^2\frac{\partial^2\pi}{\partial q^2}$$

$$= -\frac{\partial^2\pi}{\partial\gamma^2}\frac{\partial^2\pi}{\partial q^2}\frac{\partial^2\pi}{\partial z^2} + \frac{\partial^2\pi}{\partial\gamma^2}\left(\frac{\partial^2\pi}{\partial q\partial z}\right)^2 + \left(\frac{\partial^2\pi}{\partial q\partial\gamma}\right)^2\frac{\partial^2\pi}{\partial z^2} - 2\frac{\partial^2\pi}{\partial q\partial\gamma}\frac{\partial^2\pi}{\partial z\partial\gamma}\frac{\partial^2\pi}{\partial q\partial z} + \left(\frac{\partial^2 r}{\partial z\partial\gamma}\right)^2\frac{\partial^2 r}{\partial q^2}$$

$$= \frac{\partial^2\pi}{\partial\gamma^2}\left[\left(\frac{\partial^2\pi}{\partial q\partial z}\right)^2 - \frac{\partial^2\pi}{\partial q^2}\frac{\partial^2\pi}{\partial z^2}\right] + \left(\frac{\partial^2\pi}{\partial q\partial\gamma}\right)^2\frac{\partial^2\pi}{\partial z^2} - 2\frac{\partial^2\pi}{\partial q\partial\gamma}\frac{\partial^2\pi}{\partial z\partial\gamma}\frac{\partial^2\pi}{\partial q\partial z} + \left(\frac{\partial^2\pi}{\partial z\partial\gamma}\right)^2\frac{\partial^2\pi}{\partial q^2}$$

$$= M_1 + M_2 - M_3 + M_4$$

<u>(ii) M_1</u>

$$\frac{\partial^2\pi}{\partial\gamma^2}\left[\left(\frac{\partial^2\pi}{\partial q\partial z}\right)^2-\frac{\partial^2\pi}{\partial q^2}\frac{\partial^2\pi}{\partial z^2}\right]=\frac{\partial^2\pi}{\partial\gamma^2}\left[\left(\gamma\frac{\partial^2 f}{\partial z\,\partial x}\right)^2-\left(\gamma\frac{\partial^2 f}{\partial x^2}\right)\left(\gamma\frac{\partial^2 f}{\partial z^2}\right)\right]$$

$$=\frac{\partial^2\pi}{\partial\gamma^2}\gamma^2\left[\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2-\left(\frac{\partial^2 f}{\partial x^2}\right)\left(\frac{\partial^2 f}{\partial z^2}\right)\right]$$

(iii) M_2

$$\left(\frac{\partial^2\pi}{\partial q\partial\gamma}\right)^2\frac{\partial^2\pi}{\partial z^2}=\left(\frac{\partial^2\pi}{\partial q\partial\gamma}\right)^2\gamma\frac{\partial^2 f}{\partial z^2}=\left(\gamma\frac{\partial^2 f}{\partial x^2}\frac{\partial s}{\partial\gamma}\right)^2\gamma\frac{\partial^2 f}{\partial z^2}=\gamma^3\left(\frac{\partial^2 f}{\partial x^2}\frac{\partial s}{\partial\gamma}\right)^2\frac{\partial^2 f}{\partial z^2}$$

(iii) M_3

$$2\frac{\partial^2 r}{\partial q\partial\gamma}\frac{\partial^2 r}{\partial z\partial\gamma}\frac{\partial^2 r}{\partial q\partial z}=\left(\gamma\frac{\partial^2 f}{\partial x^2}\frac{\partial s}{\partial\gamma}\right)\left(\gamma\frac{\partial^2 f}{\partial z\,\partial x}\frac{\partial s}{\partial\gamma}\right)\left(\gamma\frac{\partial^2 f}{\partial z\,\partial x}\right)=2\gamma^3\left(\frac{\partial^2 f}{\partial x^2}\right)\left(\frac{\partial s}{\partial\gamma}\right)^2\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2$$

(iv) M_4

$$\left(\frac{\partial^2 r}{\partial z\partial\gamma}\right)^2\frac{\partial^2 r}{\partial q^2}=\left(\gamma\frac{\partial^2 f}{\partial z\,\partial x}\frac{\partial s}{\partial\gamma}\right)^2\left(\gamma\frac{\partial^2 f}{\partial x^2}\right)=\gamma^3\left(\frac{\partial^2 f}{\partial z\,\partial x}\frac{\partial s}{\partial\gamma}\right)^2\left(\frac{\partial^2 f}{\partial x^2}\right)$$

$$=\gamma^3\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2\left(\frac{\partial s}{\partial\gamma}\right)^2\left(\frac{\partial^2 f}{\partial x^2}\right)$$

(v) There is a clear pattern in M_3 and M_4:

$$-M_3+M_4=-2\gamma^3\left(\frac{\partial^2 f}{\partial x^2}\right)\left(\frac{\partial s}{\partial\gamma}\right)^2\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2+\gamma^3\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2\left(\frac{\partial s}{\partial\gamma}\right)^2\left(\frac{\partial^2 f}{\partial x^2}\right)$$

$$=-\gamma^3\left(\frac{\partial^2 f}{\partial x^2}\right)\left(\frac{\partial s}{\partial\gamma}\right)^2\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2$$

(vi) Retaking the expression $M_1+M_2-M_3+M_4$, and incorporating (ii)-(v):

$$\Delta=M_1+M_2-M_3+M_4=$$

$$\frac{\partial^2\pi}{\partial\gamma^2}\gamma^2\left[\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2-\left(\frac{\partial^2 f}{\partial x^2}\right)\left(\frac{\partial^2 f}{\partial z^2}\right)\right]+\gamma^3\left(\frac{\partial^2 f}{\partial x^2}\frac{\partial s}{\partial\gamma}\right)^2\frac{\partial^2 f}{\partial z^2}-\gamma^3\left(\frac{\partial^2 f}{\partial x^2}\right)\left(\frac{\partial s}{\partial\gamma}\right)^2\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2=$$

$$\frac{\partial^2\pi}{\partial\gamma^2}\gamma^2\left[\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2-\left(\frac{\partial^2 f}{\partial x^2}\right)\left(\frac{\partial^2 f}{\partial z^2}\right)\right]+\gamma^3\frac{\partial^2 f}{\partial x^2}\left(\frac{\partial s}{\partial\gamma}\right)^2\left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2}-\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2\right]=$$

$$\left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2}-\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2\right]\left[\gamma^3\frac{\partial^2 f}{\partial x^2}\left(\frac{\partial s}{\partial\gamma}\right)^2-\frac{\partial^2\pi}{\partial\gamma^2}\gamma^2\right]=$$

$$\gamma^2\left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2}-\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2\right]\left[\gamma\frac{\partial^2 f}{\partial x^2}\left(\frac{\partial s}{\partial\gamma}\right)^2-\frac{\partial^2\pi}{\partial\gamma^2}\right]$$

(vii) Now, it is necessary to introduce the expression that corresponds to second order partial derivative of π in respect to γ, i.e. $\frac{\partial^2\pi}{\partial\gamma^2}$ (appendix A.2.2).Taking it to (vi) yields:

$$\Delta = A + B - C + D =$$

$$\gamma^2\left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2} - \left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2\right]\left[\gamma\frac{\partial^2 f}{\partial x^2}\left(\frac{\partial s}{\partial \gamma}\right)^2 - w\left(2\frac{\partial s}{\partial \gamma} + \frac{\partial^2 s}{\partial \gamma^2}\gamma\right) + \gamma\frac{\partial^2 f}{\partial x^2}\left(\frac{\partial s}{\partial \gamma}\right)^2\right] =$$

$$\gamma^2\left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2} - \left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2\right]\left[-w\left(2\frac{\partial s}{\partial \gamma} + \frac{\partial^2 s}{\partial \gamma^2}\gamma\right)\right] \rightarrow$$

$$\Delta = -w\gamma^2\left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2} - \left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2\right]\left[\left(2\frac{\partial s}{\partial \gamma} + \frac{\partial^2 s}{\partial \gamma^2}\gamma\right)\right]$$

The first term, in brackets, is non-negative by SOC5. Owing to the fact that the expression evaluated is the numerator of a fraction, it is necessary to assume SOC5 applies strictly, what imposes no loss of generality. The second term in brackets is negative by definition of the function s (see SOC3 and SOC4). One ends, finally, to the conclusion that Δ is positive (its sign does not influence the sign of the terms of the Hessian matrix's inverse).

A.2.3.2 $\boldsymbol{D_q f(\bar{x};\bar{q})}$

The matrix $D_q f(\bar{x};\bar{q})$ consists into the matrix of partial derivatives of the left side of the FOCs in function of the parameters of interest, in the case, only w and c. I.e.:

$$D_q f(\bar{x};\bar{q}) = \begin{bmatrix} \frac{\partial}{\partial w}\left(\frac{\partial\pi}{\partial\gamma}\right) & \frac{\partial}{\partial c}\left(\frac{\partial\pi}{\partial\gamma}\right) \\ \frac{\partial}{\partial w}\left(\frac{\partial\pi}{\partial q}\right) & \frac{\partial}{\partial c}\left(\frac{\partial\pi}{\partial q}\right) \\ \frac{\partial}{\partial w}\left(\frac{\partial\pi}{\partial z}\right) & \frac{\partial}{\partial c}\left(\frac{\partial\pi}{\partial z}\right) \end{bmatrix} \rightarrow$$

$$D_q f(\bar{x};\bar{q}) = \begin{bmatrix} \frac{\partial}{\partial w}\left(\hat{\pi} + \gamma\frac{\partial f}{\partial x}\frac{\partial s}{\partial \gamma}\right) & \frac{\partial}{\partial c}\left(\hat{\pi} + \gamma\frac{\partial f}{\partial x}\frac{\partial s}{\partial \gamma}\right) \\ \frac{\partial}{\partial w}\left(\gamma\left[\frac{\partial f}{\partial x} - w\right]\right) & \frac{\partial}{\partial c}\left(\gamma\left[\frac{\partial f}{\partial x} - w\right]\right) \\ \frac{\partial}{\partial w}\left(\gamma\left[\frac{\partial f}{\partial z} - c\right]\right) & \frac{\partial}{\partial c}\left(\gamma\left[\frac{\partial f}{\partial z} - c\right]\right) \end{bmatrix} \rightarrow$$

$$D_q f(\bar{x};\bar{q}) = \begin{bmatrix} \frac{\partial}{\partial w}[f(s(\gamma,\Omega) + q, z) - cz - wq] & \frac{\partial}{\partial c}[f(s(\gamma,\Omega) + q, z) - cz - wq] \\ -\gamma & 0 \\ 0 & -\gamma \end{bmatrix} \rightarrow$$

$$D_q f(\bar{x};\bar{q}) = \begin{bmatrix} -q & -z \\ -\gamma & 0 \\ 0 & -\gamma \end{bmatrix}$$

A.2.3.3 Gathering A.2.3.1 and A.2.3.2:

$$D_q\eta(\bar{q}) = -D_x f(\bar{x};\bar{q})^{-1} D_q f(\bar{x};\bar{q})$$

$$D_q\eta(\bar{q}) = -\begin{bmatrix} E^2 - DF & BF - CE & CD - BE \\ BF - CE & C^2 - AF & AE - BC \\ CD - BE & AE - BC & B^2 - AD \end{bmatrix}\begin{bmatrix} -\mathrm{q} & -\mathrm{z} \\ -\gamma & 0 \\ 0 & -\gamma \end{bmatrix} \rightarrow$$

$$D_q\eta(\bar{q}) = \begin{bmatrix} E^2 - DF & BF - CE & CD - BE \\ BF - CE & C^2 - AF & AE - BC \\ CD - BE & AE - BC & B^2 - AD \end{bmatrix}\begin{bmatrix} \mathrm{q} & \mathrm{z} \\ \gamma & 0 \\ 0 & \gamma \end{bmatrix} \rightarrow$$

$$D_q\eta(\bar{q}) = \begin{bmatrix} (E^2 - DF)\mathrm{q} + (BF - CE)\gamma & (E^2 - DF)\mathrm{z} + (CD - BE)\gamma \\ (BF - CE)q + (C^2 - AF)\gamma & (BF - CE)z + (AE - BC)\gamma \\ (CD - BE)q + (AE - BC)\gamma & (CD - BE)z + (B^2 - AD)\gamma \end{bmatrix}$$

<u>(i) $(E^2 - DF)$</u>

$$E^2 - DF = \left(\frac{\partial^2\pi}{\partial q\partial z}\right)^2 - \frac{\partial^2\pi}{\partial q^2}\frac{\partial^2\pi}{\partial z^2} = \left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\right)^2 - \left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\right)\left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}^2}\right)$$

$$= \gamma^2\left[\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\right)^2 - \left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\right)\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}^2}\right)\right]$$

By SOC5, this term must be nonpositive. But, for the hessian matrix to be invertible, it cannot be zero. Then, the expression obtained is negative.

<u>(ii) $(BF - CE)$</u>

$$BF - CE = \frac{\partial^2\pi}{\partial q\partial\gamma}\frac{\partial^2\pi}{\partial z^2} - \frac{\partial^2\pi}{\partial z\partial\gamma}\frac{\partial^2\pi}{\partial q\partial z} = \gamma\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\frac{\partial \mathrm{s}}{\partial\gamma}\right)\left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}^2}\right) - \left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\frac{\partial \mathrm{s}}{\partial\gamma}\right)\left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\right)$$

$$= \gamma^2\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\frac{\partial \mathrm{s}}{\partial\gamma}\right)\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}^2}\right) - \gamma^2\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\right)^2\left(\frac{\partial \mathrm{s}}{\partial\gamma}\right) = \left(\gamma^2\frac{\partial \mathrm{s}}{\partial\gamma}\right)\left[\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}^2} - \left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\right)^2\right]$$

By SOC5, the sign of BF - CE has to be nonpositive (given that $\frac{\partial \mathrm{s}}{\partial\gamma}$ is always negative). But, again, coherence with the non-singularity of the hessian requires that the term be negative.

<u>(iii) $(E^2 - DF)\mathrm{q} + (BF - CE)\gamma$</u>

$(E^2 - DF)\mathrm{q} + (BF - CE)\gamma$

$$= \gamma^2\left[\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\right)^2 - \left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\right)\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}^2}\right)\right]q + \left(\gamma^2\frac{\partial \mathrm{s}}{\partial\gamma}\right)\left[\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}^2} - \left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\right)^2\right]\gamma$$

$$= \gamma^2\left[\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\right)^2 - \left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\right)\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}^2}\right)\right]\left(q - \gamma\frac{\partial \mathrm{s}}{\partial\gamma}\right)$$

Again, by SOC5, the term in brackets is nonpositive, and, consequently $(E^2 - DF)\text{q} + (BF - CE)\gamma$ is also nonpositive. But, for the hessian to be invertible, the term must be negative.

(iv) CD – BE

$$CD - BE = \frac{\partial^2\pi}{\partial z\partial\gamma}\frac{\partial^2\pi}{\partial q^2} - \frac{\partial^2\pi}{\partial q\partial\gamma}\frac{\partial^2\pi}{\partial q\partial z} = \left(\gamma\frac{\partial^2 f}{\partial z\,\partial x}\frac{\partial s}{\partial\gamma}\right)\left(\gamma\frac{\partial^2 f}{\partial x^2}\right) - \left(\gamma\frac{\partial^2 f}{\partial x^2}\frac{\partial s}{\partial\gamma}\right)\left(\gamma\frac{\partial^2 f}{\partial z\,\partial x}\right)$$

$$= \gamma^2\frac{\partial^2 f}{\partial x^2}\frac{\partial s}{\partial\gamma}\frac{\partial^2 f}{\partial z\,\partial x} - \gamma^2\frac{\partial^2 f}{\partial x^2}\frac{\partial s}{\partial\gamma}\frac{\partial^2 f}{\partial z\,\partial x} = 0$$

(v) $(E^2 - DF)\text{z} + (CD - BE)\gamma$

$$(E^2 - DF)\text{z} + (CD - BE)\gamma = \gamma^2\left[\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2 - \left(\frac{\partial^2 f}{\partial x^2}\right)\left(\frac{\partial^2 f}{\partial z^2}\right)\right]\text{z}$$

Following the last results, this term has to be negative.

(vi) C^2 - AF

$$C^2 - AF = \left(\frac{\partial^2\pi}{\partial z\partial\gamma}\right)^2 - \frac{\partial^2\pi}{\partial\gamma^2}\frac{\partial^2\pi}{\partial z^2}$$

$$= \left(\gamma\frac{\partial^2 f}{\partial z\,\partial x}\frac{\partial s}{\partial\gamma}\right)^2 - \left[\text{w}\left(2\frac{\partial s}{\partial\gamma} + \frac{\partial^2 s}{\partial\gamma^2}\gamma\right) + \gamma\frac{\partial^2 f}{\partial x^2}\left(\frac{\partial s}{\partial\gamma}\right)^2\right]\gamma\frac{\partial^2 f}{\partial z^2} =$$

$$\gamma^2\left(\frac{\partial s}{\partial\gamma}\right)^2\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2 - \text{w}\gamma\left(2\frac{\partial s}{\partial\gamma} + \frac{\partial^2 s}{\partial\gamma^2}\gamma\right)\frac{\partial^2 f}{\partial z^2} - \gamma^2\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2}\left(\frac{\partial s}{\partial\gamma}\right)^2$$

$$= \gamma^2\left(\frac{\partial s}{\partial\gamma}\right)^2\left[\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2 - \frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2}\right] - \text{w}\gamma\left(2\frac{\partial s}{\partial\gamma} + \frac{\partial^2 s}{\partial\gamma^2}\gamma\right)\frac{\partial^2 f}{\partial z^2}$$

The term in brackets is nonpositive, by SOC5. The second term is negative, according to SOC3 and SOC4. Therefore, $C^2 - AF$ is negative.

(vii) $(BF - CE)q + (C^2 - AF)\gamma$

$$(BF - CE)q + (C^2 - AF)\gamma$$

$$= \left(\gamma^2\frac{\partial s}{\partial\gamma}\right)\left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2} - \left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2\right]q + \gamma^3\left(\frac{\partial s}{\partial\gamma}\right)^2\left[\left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2 - \frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2}\right]$$

$$- \text{w}\gamma\left(2\frac{\partial s}{\partial\gamma} + \frac{\partial^2 s}{\partial\gamma^2}\gamma\right)\frac{\partial^2 f}{\partial z^2}$$

$$= \gamma^2\left[\frac{\partial^2 f}{\partial x^2}\frac{\partial^2 f}{\partial z^2} - \left(\frac{\partial^2 f}{\partial z\,\partial x}\right)^2\right]\left[\frac{\partial s}{\partial\gamma}q - \gamma\left(\frac{\partial s}{\partial\gamma}\right)^2\right] - \text{w}\gamma\left(2\frac{\partial s}{\partial\gamma} + \frac{\partial^2 s}{\partial\gamma^2}\gamma\right)\frac{\partial^2 f}{\partial z^2}$$

By SOCs 3-5, the term is negative.

(viii) AE-BC

$$AE - BC = \frac{\partial^2\pi}{\partial\gamma^2}\frac{\partial^2\pi}{\partial q\partial z} - \frac{\partial^2\pi}{\partial q\partial\gamma}\frac{\partial^2\pi}{\partial z\partial\gamma}$$

$$= \left[\mathrm{w}\left(2\frac{\partial \mathrm{s}}{\partial\gamma} + \frac{\partial^2 \mathrm{s}}{\partial\gamma^2}\gamma\right) + \gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\left(\frac{\partial \mathrm{s}}{\partial\gamma}\right)^2\right]\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}} - \left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\frac{\partial \mathrm{s}}{\partial\gamma}\gamma\right)\left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\frac{\partial \mathrm{s}}{\partial\gamma}\right)$$

$$= \left[\mathrm{w}\left(2\frac{\partial \mathrm{s}}{\partial\gamma} + \frac{\partial^2 \mathrm{s}}{\partial\gamma^2}\gamma\right) + \gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\left(\frac{\partial \mathrm{s}}{\partial\gamma}\right)^2\right]\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}} - \gamma^2\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\left(\frac{\partial \mathrm{s}}{\partial\gamma}\right)^2\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}$$

$$= \mathrm{w}\left(2\frac{\partial \mathrm{s}}{\partial\gamma} + \frac{\partial^2 \mathrm{s}}{\partial\gamma^2}\gamma\right)\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}} + \gamma^2\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\left(\frac{\partial \mathrm{s}}{\partial\gamma}\right)^2\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}} - \gamma^2\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\left(\frac{\partial \mathrm{s}}{\partial\gamma}\right)^2\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}$$

$$= \mathrm{w}\left(2\frac{\partial \mathrm{s}}{\partial\gamma} + \frac{\partial^2 \mathrm{s}}{\partial\gamma^2}\gamma\right)\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}} \rightarrow S(AE - BC) = (-1)S\left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\right)$$

Where S(.) is the function which gives the sign of its argument (sign function). The result called Wicksell's law, by Simon & Blume (2005, p.492), states that the cross-derivative is of a homogeneous functions with decreasing marginal returns is always positive (what is an extension of Euler's Formula for second order derivatives). This way, it can be concluded that the signal of the expression here obtained is negative.

(ix) $(BF - CE)z + (AE - BC)\gamma$

$$(BF - CE)z + (AE - BC)\gamma = \left(\gamma^2\frac{\partial \mathrm{s}}{\partial\gamma}\right)\left[\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}^2} - \left(\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}\right)^2\right]z + \mathrm{w}\left(2\frac{\partial \mathrm{s}}{\partial\gamma} + \frac{\partial^2 \mathrm{s}}{\partial\gamma^2}\right)\gamma^2\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}$$

Being the first term nonpositive and the second term negative, this expression is surely negative.

(x) $(CD - BE)z + (AE - BC)\gamma$

$$(CD - BE)z + (AE - BC) = \mathrm{w}\left(2\frac{\partial \mathrm{s}}{\partial\gamma} + \frac{\partial^2 \mathrm{s}}{\partial\gamma^2}\gamma\right)\gamma^2\frac{\partial^2 \mathrm{f}}{\partial \mathrm{z}\,\partial \mathrm{x}}$$

This expression has a negative sign (reminding the results obtained in the last steps).

(xi)B^2 – AD:

$$B^2 - AD = \left(\frac{\partial^2\pi}{\partial q\partial\gamma}\right)^2 - \frac{\partial^2\pi}{\partial\gamma^2}\frac{\partial^2\pi}{\partial q^2} = \left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\frac{\partial \mathrm{s}}{\partial\gamma}\right)^2 - \left[\mathrm{w}\left(2\frac{\partial \mathrm{s}}{\partial\gamma} + \frac{\partial^2 \mathrm{s}}{\partial\gamma^2}\gamma\right) + \gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\left(\frac{\partial \mathrm{s}}{\partial\gamma}\right)^2\right]\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}$$

$$=$$

$$= \left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\frac{\partial \mathrm{s}}{\partial\gamma}\right)^2 - \mathrm{w}\left(2\frac{\partial \mathrm{s}}{\partial\gamma} + \frac{\partial^2 \mathrm{s}}{\partial\gamma^2}\gamma\right)\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2} - \left(\gamma\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}\frac{\partial \mathrm{s}}{\partial\gamma}\right)^2 = -\mathrm{w}\gamma\left(2\frac{\partial \mathrm{s}}{\partial\gamma} + \frac{\partial^2 \mathrm{s}}{\partial\gamma^2}\gamma\right)\frac{\partial^2 \mathrm{f}}{\partial \mathrm{x}^2}$$

$$\rightarrow \mathrm{B}^2 - \mathrm{AD} < 0$$

(xii) $(CD - BE)z + (B^2 - AD)\gamma$

$$(CD - BE)z + (B^2 - AD)\gamma = -w\gamma\left(2\frac{\partial s}{\partial \gamma} + \frac{\partial^2 s}{\partial \gamma^2}\gamma\right)\frac{\partial^2 f}{\partial x^2} < 0$$

As already stablished.

A.2.3.4 The result

$$S[D_q\eta(\bar{q})] = \begin{bmatrix} S\left(\frac{\partial \gamma^*}{\partial w}\right) & S\left(\frac{\partial \gamma^*}{\partial c}\right) \\ S\left(\frac{\partial q^*}{\partial w}\right) & S\left(\frac{\partial q^*}{\partial c}\right) \\ S\left(\frac{\partial z^*}{\partial w}\right) & S\left(\frac{\partial z^*}{\partial c}\right) \end{bmatrix} = \begin{bmatrix} -1 & -1 \\ -1 & -1 \\ -1 & -1 \end{bmatrix}$$

APPENDIX A.2.4 SEMI-STRUCTURED SURVEY IN AN AGRARIAN SETTLEMENT, EASTERN AMAZONIA, STATE OF PARÁ, BRAZIL (MARCH 19-22, 2012), CHAPTER 2

Semi-structured interviews were carried out between 19 and 22 March 2012 with representatives of public and private institutions, in a municipality of the southeast of Pará state – the Brazilian Agriculture Research Corporation (EMBRAPA), State and municipal agriculture secretaries (SAGRI and SEMAGRI, respectively), rural workers union (STTR) and the local office of the public enterprise of rural extension (EMATER) - and smallholders of an agrarian settlement located 80 km away from the municipal capital. A total of 5 institutional representatives and 15 settlers were interview.

No particular criterion was follow to select the settlers to be interviewed, besides the recommendation of other interviewees. For instance, the representative of the rural workers union suggested the interview of two smallholders, one of them with an institutional position in the settlement and the other being a successful/innovative agricultural producer. These two interviewees pointed out to other interviewees, and so forth. Box C, at the end of this appendix, give the detailed interview guide.

Holding lots of 25 hectares in total, the interviewed settlers allocate, in average, one hectare per year for the growing of annual crops for own-consumption. Generally grains (rice, cowpea, maize and rice) and tubers (cassava, mostly). All of them produce cassava flour for consumption, in small self-built facilities (*"casas de farinha"*), reserving an irregular fraction for sale. Eight of the fifteen respondents raise dairy cattle and one of them raises calves for selling. Small initiatives of fruit production (watermelon, citrus) could be also observed, as well as horticulture and production of mauve. The planting of trees is practiced with arboreal landscaping purposes (amenities), to give support to other land uses (shading) and for the provision of firewood. It is limited to "homegardens", located around the farmers, which also provide fruits. In these, the chestnut (*Bertholletia excelsa*) and Cupuaçú trees (*Theobroma grandiflorum*) are always present.

Most respondents (ten out of fifteen) have being in the farms for at least 12 years and have additional sources of income besides the agriculture (eleven out of thirteen). Pensions and government transfers (through the program *"Bolsa Família"* and *"Bolsa Escola"*), overall.

The main components of the agricultural income generated by settlement as a whole, are, in decreasing order of importance, nuts and Cupuaçu fruit (extractivism).

The area where the settlement is located had been used for several decades before settlement's establishment in 1997. Smallholders have accessed a worn soil since from the beginning and primary vegetation was already completely suppressed.

Fire is the technical basis of agricultural production in the settlement, being used with three purposes: (i) prepare the soil for planting maize, beans and cassava (ii) kill pastures overrun with weeds and (iii) prepare the land for the use of tractors, after the suppression of secondary vegetation. All respondents said they take all the care needed in order to prevent accidental fires, by communicating neighbors, constructing firebreaks and burning not before the 4 pm. However, most interviewees declared to either have being victims of accidental farmers or the agent behind them. The head of the association that centralizes the political representation of settlers, reported to have taken part, several times, as mediator, in conflicts between settlers around the sharing of losses. Nearly all the settlers believe accidental fires were reduced after a fire brigade from the federal environmental agency (IBAMA) start supervising fire use during the burn season (September and November) by the competent.

Since the year of 2010, tractors and operators were made available with no cost by the municipal agriculture department. The goal envisioned is to create favorable conditions for the replacement of slash-and-burn for an itinerary based on inputs (fertilizers, mainly) and machinery, what is locally denoted as "mechanized soil preparation" or simply "mechanization". The municipal government has nine tractors, but only two of them are reserved for the settlement.

To use the service, the settler has to request the inclusion of his/her name in a list, managed by the association of the community where the farm is located (the settlement is divided into five several communities and covers a total area around 33.000 hectares). The lists elaborated by the associations are subjected to a screening by the central association. In the third step, the technician (extensionist) that is in charge of planning the schedule of tractor sharing among settlers let them know about the time where they will (possibly) be attended, i.e., at what day the tractor will be at their door. The cost of mechanized soil preparation is shared among SEMAGRI, SAGRI and settler as follows. Limestone is donated by SAGRI, the transport cost is paid by SEMAGRI and the fertilizers (NPK and urea) and freight transport are covered exclusively by settlers, as well as the oil that fuels the tractor.

Box	**Interview guide for settlers**
A	**Socioeconomic background**
A.1	When do you/your family arrived in this land?
A.2	What are the main activities developed in the farm?
A.3	What are your main income sources?
B	**Fire use**
B.1	What is the rationale of fire use in general?
B.2	Which are the particular reasons for which you use fire or for which you do not use fire?
B.3	Have you ever being exposed to accidental fires started in the neighborhood? What were the damages caused? How the loss was shared between you and your neighbors?
B.4	Have you ever caused accidental fire spreads? What were the damages caused? How the loss was shared between you and your neighbors?
C	**Shift to mechanized soil clearing and fertilizer-based cropping**
C.1	Why have you joined the mechanization program?
C.2	What are the main advantages of the program?
C.3	How is the work schedule on mechanized cropping?
C.4	Which procedures are implemented to correct and fertilize the soil?
C.5	How the mechanized production compares with the past slash-and-burn based production?

APPENDIX A.3.1 ESTIMATION RESULTS, CHAPTER 3

Table A.3.1 Estimation results for the 1km neighborhood subsample

	[1]	[2]	[3]	[4]	[5]
	epro	**mliv**	**iv2S**	**sarar**	**sarariv**
w_cps_own	-0.00533***		0.01285	-0.00054***	-0.00069*
	(0.00086)		(0.00913)	(0.00009)	(0.0003)
w_cps_2nd	-0.00153		-0.00029	-0.00006	0.0004
	(0.00121)		(0.00899)	(0.00012)	(0.00044)
crop	0.02227***		0.00084	0.00351***	0.00382***
	(0.00231)		(0.01022)	(0.00032)	(0.00071)
past	0.01826***		-0.0052	0.00242***	0.00278***
	(0.00177)	DOES NOT CONVERGE	(0.01019)	(0.00022)	(0.0006)
silv	0.03312		-0.00402	0.00417	0.00435
	(0.01892)		(0.0346)	(0.00247)	(0.00361)
fore	-0.00314		0.00496	-0.00011	0.00012
	(0.00165)		(0.00837)	(0.00015)	(0.00021)
d_roads	-0.00659		-0.00257	0.00004	0.00012
	(0.00441)		(0.00532)	(0.00056)	(0.00043)
_cons	-1.59060***		-2.45417**	0.0166	-0.00594
	(0.09846)		(0.77024)	(0.01238)	(0.01344)
λ	DA	DA	DA	20.39425***	24.61291***
				(3.23982)	(6.25017)
ρ	DA	DA	DA	13.22820**	-0.34173
				(4.43228)	(10.06356)
N	3420	DA	3420	3420	3420
chi2	199.8824	DA	148.69411	224.3337	
chi2_exog		DA	4.10824		
p_exog		DA	0.12821		

DA stands for “does not apply”, EPRO = endogenous probit, MLIV = maximum likelihood instrumental variable probit, IV2S = two stage minimum chi-square instrumental variable probit with bootstrapped residuals, SARAR = spatial autoregressive linear model with spatial error component (binary dependent variable), SARARIV = instrumental variable spatial autoregressive linear model with spatial error component (binary dependent variable).

Table A.3.2 Estimation results for the 2km neighborhood subsample

	[1]	[2]	[3]	[4]	[5]
	epro	**mliv**	**iv2S**	**sarar**	**sarariv**
w_cps_own	-0.00226***		-0.00204	-0.00024***	-0.00027***
	(0.00024)		(0.00195)	(0.00003)	(0.00004)
w_cps_2nd	-0.00051*		0.0002	-0.00005*	0.00015**
	(0.00021)		(0.00152)	(0.00002)	(0.00006)
crop	0.02206***		0.02191**	0.00348***	0.00382***
	(0.00173)		(0.00706)	(0.00024)	(0.00041)
past	0.01913***		0.01878*	0.00252***	0.00280***
	(0.00143)	DOES NOT CONVERGE	(0.00772)	(0.00017)	(0.00028)
silv	0.01571*		0.01445	0.00155	0.00162
	(0.00707)		(0.02185)	(0.00101)	(0.00094)
fore	-0.00367**		-0.00183	-0.00018	0.00024
	(0.00117)		(0.00449)	(0.00012)	(0.00014)
d_roads	-0.00619		-0.00581	0.00001	0.00019
	(0.0037)		(0.00413)	(0.00056)	(0.0004)
_cons	-1.43842***		-1.65822**	0.03497**	-0.02228
	(0.08911)		(0.57008)	(0.01302)	(0.01358)
λ	DA	DA	DA	16.60900***	21.67783***
				(1.92008)	(4.15643)
ρ	DA	DA	DA	13.46597***	0.97709
				(2.54595)	(4.5356)
N	4910	DA	4910	4910	4910
chi2	326.54163	DA	304.3741	409.65486	
chi2_exog		DA	0.13026		
p_exog		DA	0.93695		

Table A.3.3 Estimation results for the 3km neighborhood subsample

	[1]	[2]	[3]	[4]	[5]
	epro	**mliv**	**iv2S**	**sarar**	**sarariv**
w_cps_own	-0.00104***	-0.00244***	-0.00273**	-0.00011***	-0.00011***
	(0.00011)	(0.00048)	(0.001)	(0.00001)	(0.00002)
w_cps_2nd	-0.00024**	-0.00065	-0.00072	-0.00003*	0.00003
	(0.00008)	(0.00038)	(0.00069)	(0.00001)	(0.00002)
crop	0.02147***	0.02851***	0.03204***	0.00356***	0.00369***
	(0.00151)	(0.00238)	(0.0064)	(0.00022)	(0.00037)
past	0.01809***	0.02655***	0.02981***	0.00243***	0.00247***
	(0.00124)	(0.00266)	(0.00707)	(0.00015)	(0.00022)
silv	0.01219	0.02480**	0.02777	0.00116	0.00115
	(0.0067)	(0.008)	(0.02661)	(0.00094)	(0.00076)
fore	-0.00237*	-0.00467*	-0.00522	-0.00003	0.00019
	(0.00105)	(0.00202)	(0.00392)	(0.00011)	(0.00011)
d_roads	-0.00732*	-0.00918**	-0.01032***	0.00001	0.00027
	(0.0035)	(0.00312)	(0.00302)	(0.00061)	(0.00044)
_cons	-1.44975***	-0.60834	-0.69914	0.03231*	-0.01252
	(0.08717)	(0.46445)	(0.64694)	(0.01403)	(0.01422)
λ	DA	DA	DA	15.64213***	23.04613***
				(1.64922)	(4.00924)
ρ	DA	DA	DA	15.26277***	5.41916
				(1.82875)	(2.97012)
N	5432	5432	5432	5432	5432
chi2	400.68484	580.9534	227.10861	468.89016	
chi2_exog		7.44229	3.54329		
p_exog		0.00637	0.17005		

Table A.3.4 Estimation results for the 4km neighborhood subsample

	[1]	[2]	[3]	[4]	[5]
	epro	**mliv**	**iv2S**	**sarar**	**sarariv**
w_cps_own	-0.00065***	-0.00171***	-0.00198***	-0.00007***	-0.00007***
	(0.00007)	(0.00019)	(0.00059)	(0.00001)	(0.00002)
w_cps_2nd	-0.00012**	-0.00027	-0.00031	-0.00001*	0.00002
	(0.00004)	(0.00019)	(0.0003)	(0.00001)	(0.00002)
crop	0.02043***	0.02768***	0.03197***	0.00344***	0.00367***
	(0.00141)	(0.00182)	(0.00542)	(0.00021)	(0.0004)
past	0.01643***	0.02388***	0.02758***	0.00220***	0.00225***
	(0.00114)	(0.00146)	(0.00507)	(0.00014)	(0.0002)
silv	0.00847	0.02041**	0.02352	0.00077	0.00082
	(0.00605)	(0.00622)	(0.01201)	(0.00082)	(0.00069)
fore	-0.00207*	-0.00304	-0.00351	0.00001	0.00017
	(0.00103)	(0.0018)	(0.00271)	(0.00011)	(0.00011)
d_roads	-0.006	-0.00756*	-0.00874*	0.00008	0.00026
	(0.00337)	(0.00295)	(0.00346)	(0.00064)	(0.00059)
_cons	-1.46882***	-0.61231	-0.71356	0.03037*	-0.00628
	(0.09062)	(0.33999)	(0.53198)	(0.015)	(0.02036)
λ	DA	DA	DA	15.25291***	16.52904***
				(1.57351)	(3.83319)
ρ	DA	DA	DA	15.85619***	49.54337***
				(1.56239)	(4.02888)
N	5604	5604	5604	5604	5604
chi2	424.42058	676.06219	347.06854	464.24392	
chi2_exog		27.70665	6.82468		
p_exog		<0.01%	0.03296		

Table A.3.5 Estimation results for the 5km neighborhood subsample

	[1]	[2]	[3]	[4]	[5]
	epro	**mliv**	**iv2S**	**sarar**	**sarariv**
w_cps_own	-0.00045***	DOES NOT CONVERGE	-0.00108***	-0.00004***	-0.00007***
	(0.00006)		(0.00032)	(0.00001)	(0.00001)
w_cps_2nd	-0.00007*		-0.00009	-0.00001	0.00001
	(0.00003)		(0.00013)	(0.00001)	(0.00001)
crop	0.01963***		0.02667***	0.00341***	0.00361***
	(0.00137)		(0.00392)	(0.00022)	(0.00032)
past	0.01531***		0.02109***	0.00205***	0.00213***
	(0.00108)		(0.00315)	(0.00014)	(0.00018)
silv	0.00641		0.01483	0.00058	0.00071
	(0.00606)		(0.03168)	(0.00081)	(0.00066)
fore	-0.00139		-0.00078	0.00008	0.00018
	(0.00102)		(0.00205)	(0.00011)	(0.00009)
d_roads	-0.00518		-0.00588	<0.001%	-0.00009
	(0.00332)		(0.00368)	(0.00089)	(0.00032)
_cons	-1.49592***		-1.14588***	0.03788	0.0059
	(0.09417)		(0.32326)	(0.01936)	(0.01162)
λ	DA	DA	DA	12.56466***	17.35891***
				(1.85726)	(2.61463)
ρ	DA	DA	DA	22.52274***	67.32796***
				(0.58625)	(6.14064)
N	5645	DA	5645	5645	5645
chi2	411.05535	DA	339.93623	440.32911	
chi2_exog		DA	5.02497		
p_exog		DA	0.08107		

Table A.3.6 Estimation results for the 6km neighborhood subsample

	[1]	[2]	[3]	[4]	[5]
	epro	**mliv**	**iv2S**	**sarar**	**sarariv**
w_cps_own	-0.00039***	-0.00069***	-0.00071***	-0.00003***	-0.00007***
	(0.00005)	(0.0002)	(0.00021)	(0.00001)	(0.00001)
w_cps_2nd	-0.00004*	0.00005	0.00005	-0.00001	<0.001%
	(0.00002)	(0.00008)	(0.00008)	(0)	(0.00001)
crop	0.01938***	0.02288***	0.02363***	0.00336***	0.00352***
	(0.00135)	(0.00232)	(0.00294)	(0.00021)	(0.00034)
past	0.01483***	0.01694***	0.01750***	0.00200***	0.00207***
	(0.00105)	(0.00165)	(0.00202)	(0.00014)	(0.00017)
silv	0.00475	0.00892	0.00919	0.00045	0.00057
	(0.00589)	(0.00624)	(0.02301)	(0.00076)	(0.00057)
fore	-0.00093	0.00113	0.00115	0.00011	0.00019*
	(0.00101)	(0.00165)	(0.00194)	(0.00011)	(0.00009)
d_roads	-0.00434	-0.00378	-0.00392	0.00003	-0.00014
	(0.00329)	(0.00321)	(0.00275)	(0.00089)	(0.00038)
_cons	-1.52237***	-1.54555***	-1.59705***	0.03549	0.0258
	(0.09617)	(0.2486)	(0.24067)	(0.02007)	(0.01351)
λ	DA	DA	DA	12.50344***	19.22552***
				(1.85424)	(3.24677)
ρ	DA	DA	DA	22.51630***	59.65882***
				(0.584)	(6.24347)
N	5656	5656	5656	5656	5656
chi2	418	440	538	438	
chi2_exog		3	3		
p_exog		0.08853	0.18849		

Table A.3.7 Estimation results for the 7km neighborhood subsample

	[1]	[2]	[3]	[4]	[5]
	epro	**mliv**	**iv2S**	**sarar**	**sarariv**
w_cps_own	-0.00035***	-0.00060***	-0.00062**	-0.00003***	-0.00007***
	(0.00004)	(0.00014)	(0.0002)	(0.00001)	(0.00001)
w_cps_2nd	-0.00002	0.00007	0.00007	<0.001%	<0.001%
	(0.00001)	(0.00005)	(0.00007)	(0)	(0.00001)
crop	0.01913***	0.02209***	0.02296***	0.00329***	0.00343***
	(0.00133)	(0.00188)	(0.00321)	(0.00021)	(0.00037)
past	0.01438***	0.01579***	0.01642***	0.00196***	0.00201***
	(0.00102)	(0.00127)	(0.002)	(0.00014)	(0.00017)
silv	0.00417	0.00767	0.00795	0.00038	0.00044
	(0.00597)	(0.00591)	(0.01781)	(0.00075)	(0.00056)
fore	-0.00071	0.00183	0.00189	0.00011	0.00017
	(0.001)	(0.00139)	(0.0019)	(0.00011)	(0.00009)
d_roads	-0.00359	-0.00275	-0.00287	0.00008	-0.00025
	(0.00327)	(0.0032)	(0.00274)	(0.00084)	(0.00052)
_cons	-1.54621***	-1.69648***	-1.76437***	0.03067	0.04974**
	(0.09903)	(0.19971)	(0.24943)	(0.01997)	(0.01923)
λ	DA	DA	DA	13.06011***	20.47643***
				(1.76506)	(4.3504)
ρ	DA	DA	DA	21.22779***	48.90769***
				(0.19457)	(5.26322)
N	5656	5656	5656	5656	5656
chi2	425	454	467	435	
chi2_exog		6	5		
p_exog		0.0159	0.10478		

Table A.3.8 Estimation results for the 8km neighborhood subsample

	[1]	[2]	[3]	[4]	[5]
	epro	**mliv**	**iv2S**	**sarar**	**sarariv**
w_cps_own	-0.00032***	DOES NOT CONVERGE	-0.00057***	-0.00003***	-0.00007***
	(0.00004)		(0.00013)	(0.00001)	(0.00001)
w_cps_2nd	-0.00001		0.00005	<0.001%	-0.00001
	(0.00001)		(0.00004)	(0)	(0)
crop	0.01907***		0.02263***	0.00320***	0.00337***
	(0.00133)		(0.00214)	(0.00021)	(0.00037)
past	0.01413***		0.01584***	0.00193***	0.00197***
	(0.00101)		(0.00127)	(0.00014)	(0.00018)
silv	0.00387		0.00729	0.00035	0.00034
	(0.00605)		(0.02297)	(0.00074)	(0.00055)
fore	-0.00036		0.00198	0.00013	0.00018*
	(0.00099)		(0.00148)	(0.00011)	(0.00009)
d_roads	-0.00287		-0.00202	0.00023	-0.00036
	(0.00324)		(0.00307)	(0.00067)	(0.00066)
_cons	-1.58579***		-1.76685***	0.02178	0.07218**
	(0.09913)		(0.19871)	(0.01717)	(0.02599)
λ	DA	DA	DA	14.75273***	21.79842***
				(1.57319)	(5.3743)
ρ	DA	DA	DA	16.59051***	42.21179***
				(1.29829)	(4.39695)
N	5656	DA	5656	5656	5656
chi2	429.4396	DA	482.69995	434.0592	
chi2_exog		DA	4.84989		
p_exog		DA	0.08848		

Table A.3.9 Estimation results for the 9km neighborhood subsample

	[1]	[2]	[3]	[4]	[5]
	epro	**mliv**	**iv2S**	**sarar**	**sarariv**
w_cps_own	-0.00030***	-0.00051***	-0.00053***	-0.00003***	-0.00007***
	(0.00004)	(0.0001)	(0.00011)	(0.00001)	(0.00001)
w_cps_2nd	<0.001%	0.00002	0.00002	<0.001%	-0.00001
	(0.00001)	(0.00003)	(0.00004)	<0.001%	<0.001%
crop	0.01897***	0.02154***	0.02212***	0.00318***	0.00333***
	(0.00132)	(0.0017)	(0.002)	(0.00021)	(0.00037)
past	0.01392***	0.01505***	0.01545***	0.00191***	0.00194***
	(0.001)	(0.00111)	(0.0013)	(0.00014)	(0.00018)
silv	0.00364	0.00655	0.00672	0.00031	0.00026
	(0.00611)	(0.00603)	(0.02613)	(0.00074)	(0.00054)
fore	-0.00008	0.00154	0.00158	0.00014	0.00019*
	(0.00099)	(0.00136)	(0.00134)	(0.00011)	(0.00008)
d_roads	-0.0023	-0.00102	-0.00105	0.00026	-0.00048
	(0.00322)	(0.00328)	(0.00329)	(0.00068)	(0.00078)
_cons	-1.63270***	-1.60842***	-1.65164***	0.01609	0.09450**
	(0.09886)	(0.22374)	(0.25607)	(0.01761)	(0.03088)
λ	DA	DA	DA	14.62369***	22.30068***
				(1.58856)	(6.06566)
ρ	DA	DA	DA	16.77497***	38.77112***
				(1.24877)	(3.76929)
N	5656	5656	5656	5656	5656
chi2	429	449	272	431	
chi2_exog		4	4		
p_exog		0.03458	0.13648		

Table A.3.10 Estimation results for the 10km neighborhood subsample

	[1]	[2]	[3]	[4]	[5]
	epro	**mliv**	**iv2S**	**sarar**	**sarariv**
w_cps_own	-0.00029***	-0.00047***	-0.00048***	-0.00002***	-0.00006***
	(0.00004)	(0.0001)	(0.00009)	(0.00001)	(0.00001)
w_cps_2nd	<0.001%	<0.001%	<0.001%	<0.001%	-0.00001
	(0.00001)	(0.00003)	(0.00003)	<0.001%	<0.001%
crop	0.01887***	0.02112***	0.02154***	0.00338***	0.00332***
	(0.00132)	(0.00167)	(0.00175)	(0.00022)	(0.00037)
past	0.01373***	0.01486***	0.01515***	0.00193***	0.00194***
	(0.001)	(0.00107)	(0.00118)	(0.00014)	(0.00018)
silv	0.00362	0.00653	0.00666	0.00028	0.00023
	(0.00615)	(0.00619)	(0.02477)	(0.00078)	(0.00054)
fore	0.00012	0.00109	0.00111	0.00013	0.00018*
	(0.00098)	(0.00128)	(0.0013)	(0.00011)	(0.00008)
d_roads	-0.00187	0.00017	0.00017	-0.00018	-0.00042
	(0.0032)	(0.00336)	(0.00353)	(0.00106)	(0.00073)
_cons	-1.67871***	-1.49285***	-1.52248***	0.00126	0.09553***
	(0.09854)	(0.23308)	(0.2831)	(0.02737)	(0.02724)
λ	DA	DA	DA	6.14538**	18.22541**
				(2.26394)	(5.66062)
ρ	DA	DA	DA	33.01885***	40.46418***
				(0.36754)	(3.67409)
N	5656	5656	5656	5656	5656
chi2	429	440	499	434	
chi2_exog		4	4		
p_exog		0.04121	0.15982		

APPENDIX A.3.2 ROBUSTNESS TEST ESTIMATIONS, CHAPTER 3

Table A.3.11 z = $\hat{\beta} / \sigma_{\hat{\beta}}$ for own-CPS area

Neighborhood definition / Simulation	2000	3000	4000	5000	6000
1	-1.1416	-0.7311	-0.0520	-0.6852	-1.4033
2	-1.6683	-0.5732	-0.0115	-0.9546	-2.1529
3	-1.8951	-1.6985	-0.4926	-0.9156	-2.7160
4	-2.4465	-1.0535	-1.0327	-1.1275	-2.7519
5	-2.5565	-1.2888	-0.9875	-1.2830	-2.4675
6	-1.1666	-0.2072	-0.1700	-1.3157	-2.6018
7	-1.1642	-0.0761	-0.0990	-0.5573	-1.7057
8	-1.8379	-0.5828	0.0876	-1.1069	-2.4404
9	-2.1841	-0.8660	-0.8069	-1.3398	-2.2599
10	-0.5619	0.1909	0.5209	-0.1019	-0.6882
11	-0.7415	0.0624	0.5375	-0.1708	-1.1840
12	-1.8206	-0.8043	-0.2591	-0.6744	-1.2991
13	-2.7028	-1.5716	-1.2773	-1.5191	-2.7293
14	-2.0712	-0.9463	-0.0606	-0.5331	-1.9884
15	-1.9089	-0.4218	0.1584	-0.1515	-1.0837
16	-1.3332	-0.9966	-0.3322	-0.6005	-1.4966
17	-1.6531	-0.5495	-0.3749	-0.5574	-2.3341
18	-1.4604	-0.3036	-0.3189	-1.2582	-2.3060
19	-3.8612	-3.0131	-2.4770	-3.3169	-4.4285
20	-1.9047	-0.8576	-0.7294	-1.3579	-2.1456
...	...	...	...	...	...
% below 5% critical (negative) critical level	27%	4%	2%	4%	41%
Median coefficient of variation (mean / standard deviation)	- 1.66	- 0.72	- 0.32	- 0.76	- 1.81
	- 2.36	- 1.11	- 0.58	- 1.28	- 2.42

Table A.3.12 $z = \hat{\beta} / \sigma_{\hat{\beta}}$ for second party-CPS area

Neighborhood definition / Simulation	**2000**	**3000**	**4000**	**5000**	**6000**
1	1.2830	0.7780	0.3085	0.4800	0.1603
2	1.2191	0.9254	0.5435	1.2021	1.4880
3	2.7726	2.5523	0.8696	0.7474	0.9518
4	3.2964	1.6383	1.3737	1.1797	1.3359
5	2.6006	1.1383	0.7913	0.6304	0.1811
6	0.4761	0.8365	0.8124	1.3489	1.6290
7	2.3533	1.2174	0.9131	0.8177	1.1390
8	1.4140	0.3001	0.0148	0.4251	0.5317
9	1.5615	0.1244	0.2125	0.2101	0.2755
10	1.9966	0.8162	0.7802	0.7058	0.3873
11	1.0304	1.1398	0.7034	0.8615	0.5462
12	2.4713	1.5137	1.2100	1.2365	0.9183
13	3.1493	1.6743	1.2645	1.0067	1.2834
14	2.1490	1.4703	0.3766	0.3408	0.4293
15	2.4661	1.8063	0.4968	0.3325	0.6546
16	2.2878	2.3318	0.8258	0.9515	0.5876
17	2.4821	1.4001	0.6089	0.4950	0.7685
18	1.8109	1.8617	1.9117	2.4166	2.3968
19	2.7000	1.6541	0.8767	0.3861	-0.0040
20	1.9655	0.7511	0.9245	0.9640	0.7272
...	...	...	...	...	...
% below 5% critical (negative) critical level	0	0	0	0	0
Median	2.03	1.33	0.79	0.76	0.68
coefficient of variation (mean / standard deviation)	3.28	2.47	2.05	1.69	1.30

APPENDIX A.3.3 ESTIMATES FOR THE LOSS OF EFFECTIVE INCOME IMPOSED TO NEIGHBORS, CHAPTER 3

Let the estimate for total loss of effective rent be given by the equation total_loss = loss_crops + loss_pasture, each of the two components are detailed, separately in what follows.

(A) The element "loss_crops" captures the loss of the total effective income yielded by crops during one year. It is given by: loss_crops = (w_a_crop * land_rent_RASDB) /exchange_rate, where:

  i. w_a_crop, the median for the total area of crops, owned by neighbors, within a distance of 2km, amounts to zero hectares, as table A.3.13 shows;
  ii. land_rent_RASDB = median of the annual rent paid for land rental (or land leasing), as informed by table A.3.14, a proxy for the cost of opportunity of allocating land for agriculture, and amounts to R$246.00 hectares/year;
  iii. exchange rate (for the year of 2010) = R$/US$ 1.6654, as informed by the Central Bank of Brazil (BACEN: 2013).

(B) The estimation is similar to the case of loss of effective rent from crops. The only difference is that pasture does not, directly, yields profit. For this reason, it is estimated the cost of leasing pasture during three months, the time generally needed for burned pasture to recover. This follows the convention employed by Mendonça et al (2004, section 2.1.3) to estimate the cost of damages to pasture caused by accidental fires. Therefore, loss_pasture = (w_a_past * (land_rent_RASDB/4)) /exchange_rate, where:

  i. w_a_past, the median for the total area of pasture, owned by neighbors, within a distance of 2km, amounts to 60.5248 hectares, as table A.3.13 shows;
  ii. land_rent_RASDB takes the same level considered for the case of crops;
  iii. the exchange rate takes the value already mentioned.

Silviculture is disregarded in the calculus of the land use under risk of being hit by accidental fires, owing to its minor relevance: only 3 out of the 321 parcels treated with have register a non-zero second party silviculture area within a distance of 2km (table A.3.13).

The number of hectares that can be acquired with an amount of money equal to the total value of average effective income loss imposed by the neighbors, the farmland equivalent of table A.3.15, is given by total_loss / price_land. Data for the denominator also comes from RASDB, which reports two land acquisitions for the year of 2009, one for a price of US$300.23/hectare (R$500.00/hectare), the other for a value exactly twice as big (R$1,000.00/hectare).

Table A.3.13 Statistics for the area of second-party parcels within 2km allocated to the land uses indicated (crops, pasture and silviculture), RASDB

Stats/ Land use	crops	pasture	silviculture
N[a]	321	321	321
N(area = 0)[b]	219	31	318
Mean	30.6636	105.88	0.311738
SD c	89.2781	122.102	3.948902
Median	0	60.5248	0
Min	0	0	0
Max	831.945	655.669	53.41076

a Number of parcels treated with fire that belong to the sample where neighborhoods encompass 2km, at most;

b Number of parcels with zero value for the correspondent land use area that belongs to neighbors within 2km;

c Standard Deviation.

Source: RASDB

Table A.3.14 Values of leasing reported by interviewees, RASDB*

Number	R$/ha/year
1	3,200.00
2	540.00
3	306.00
4	48.00
5	230.00
6	16.67
7	245.00
8	246.00
9	300.00
Mean	**570.19**
Median	**246.00**
Standard deviation	**957.76**

* only non-missing and no-null declarations are considered.

Source: RASDB

Table A.3.15 Estimates for the loss of effective income imposed to neighbors, details

Land use	Median area	Effective income	Total R$	Total US$	Farmland equivalent	
					Minimum	Ma,imum
Crops	0	246.00	-	-	-	-
Pasture	60.52476	61.50	3,722.27	2,235.06	3.72	7.44
Silviculture	**Land use of minor importance**					
Total			**3,722.27**	**2,235.06**	**3.72**	**7.44**

Source: estimation described in this appendix.

APPENDIX A.4. 1 EVIDENCES REGARDING THE RELEVANT MARKETS FOR LAND USES' OUTPUTS, CHAPTER 4

A.3.1.1 Note "a" of 4.1 (crops)

Table A.4.1 Tabulation of the registries of the places of sales, annual crops *

Product	Count	Market				
		Missing	Local	International	National	Total
Rice	47	0%	83%	6%	11%	100%
Coconut	13	0%	100%	0%	0%	100%
Cupuaçu	12	0%	92%	0%	8%	100%
Flour	141	4%	96%	0%	0%	100%
Cassava flour	14	0%	100%	0%	0%	100%
Beans	15	13%	87%	0%	0%	100%
Orange	23	9%	91%	0%	0%	100%
Lemon	15	0%	100%	0%	0%	100%
Macaxeira	13	0%	100%	0%	0%	100%
Mandioca bruta	28	7%	93%	0%	0%	100%
Passion fruit	18	6%	94%	0%	0%	100%
Maize	106	1%	91%	2%	7%	100%
Black Pepper	52	0%	96%	0%	4%	100%
Soybean	42	2%	31%	48%	19%	100%
Total	**539**	**3%**	**88%**	**5%**	**4%**	**100%**

*Only products with a correspondent number of sale registries above the 25 percentile (10 registries) are considered.

Source: RASDB

The table shows that all crops are mainly sold at local markets. Soybean is the only exception, being sold mainly to international markets.

A.3.1.2 Note "c" of table 4.1 (cattle)

Table A.4.2 Tabulation of the registries of the places of sales, cattle

Market	Count	Percent
Missing	5	4%
Local	99	85%
International	6	5%
National	7	6%
Total	117	100%

Source: RASDB

As the tabulation above shows, the largest part of cattle sales take part on local markets, as reported by interviewees. The literature describes local markets for cattle in Brazilian Amazon as consisting basically in slaughterhouses (Bowman et al: 2012; Santos et al: 2007, Barreto et al: 2008, p.15, figure 1).

A.3.1.3 Note "d" of table 4.1 (timber from forest plantations)

From the 21 registers comprising famers' plans regarding the sale of timber from forest plantations, only three do not refer to the local market, but to the national markets – in these three registers the producers mentioned cellulose factories. The 18 other registers mentioned wood products factories (such as the MDF factory located in Paragominas), small markets (*"feira"*), selling directly to the consumers or to middlemen. What leads to the conclusion that forest plantation is a land use overall connected with local markets but also with national markets.

A.3.1.4 Note "e" of table 4.1 (timber and NTFPs from "natural forests")

Only three timber production firms were interviewed and all of them reported to have sold for local (58 out of 90 registries of timber sales) and national markets (32 out of 90 registries). Nine registries of small timber sales (below R$400.00) give further evidence on timber absorption by local markets.

For NTPFs, 32 registries of sales were reported on interviews, all of them pointing to local markets.