**Accidental fires and land use in the Brazilian Amazon: evidences from farm-level data**

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**Resumo**

Na Amazônia brasileira, incêndios causados por queimadas são ameaças constantes à agricultura, à silvicultura e ao manejo florestal sustentável. A teoria sugere que os produtores tendem a incorporar tais eventos às suas expectativas ao decidirem acerca da alocação da terra. Esta hipótese, a qual é implicitamente assumida na literatura, é submetida à refutação, tomando-se por base, para isso, dados de um levantamento detalhado conduzido em três municípios do estado do Pará. A estratégia de identificação perseguida advoga que o regime de precipitação nas proximidades é uma variável instrumental válida para a exposição a incêndios acidentais iniciados por produtores vizinhos. Resulta que os incêndios externos têm influência causal negativa sobre a área de pastagem e positiva sobre a área de floresta. Evidencia-se que o recurso a queimadas atua para reduzir o retorno econômico da utilização da terra disponível na região de estudo. O que demanda políticas envidadas à internalização dos danos causados pela prática. A mudança do clima Amazônico em curso aumenta a necessidade de avanço efetivo em tal direção.

**Palavras-chave:** Amazônia, fogo, uso da terra, variáveis instrumentais.

**Abstract**

In Brazilian Amazon, escaped fires on the vicinity of farms are constant threats to agriculture, forestry and sustainable forest management. Theory suggests that farmers tend to incorporate the probability of such occurrences to their expectations while making land use decisions. This hypothesis, which is taken for granted in the literature, is submitted to refutation by relying on detailed survey data covering three municipalities of Pará state, Brazilian Amazon. The identification strategy pursued advocates that surrounding precipitation is a valid instrumental variable for exposure to accidental fires coming from the outside. It results that external fires have a causal influence which is negative for pasture area and positive for forest area. Fires, consequently, reduce the economic returns of the utilization of the land available on the study region. Socially optimal land use can only be fostered with policies that induce fire users to internalize the damage transferred to society. Ongoing climate change on Amazon increases the need for effective progress in such direction.

**Keywords:** Amazon, fire, land use, instrumental variables.

**JEL Codes: Q12, D62, C36**

**Área ANPEC:** 11 - Economia Agrícola e do Meio Ambiente

**1 Introduction**

The widespread practice of burning slashed vegetation or degraded pasture and the non-negligible probability of losing control of the process make accidental fires a permanent threat for farmers of Brazilian Amazon (“Amazon”, hereafter) (table 1). Evidence summarized on table 1 suggest that, even with a dominant adoption of measures to prevent uncontrolled fires to spread such as building firebreaks[[1]](#footnote-1), 24 to 28% farmers were, at least once, victims of fire spreads that crossed farm boundaries.

Economic losses imposed by accidental fires on Amazon were estimated to amount to an annual average of US$21-42 million per year, considering the period of 1996 to 1999 (Mendonça et al, 2004).

In the scenario where fire use is not dramatically reduced in the future, the losses caused by accidental fires can increase considerably according with climate change forecasts of 20% rainfall reduction and 2-8°C of rise in the temperature by the end of the century (Nepstad, 2007, Coe et al, 2014). Droughts tend to become more probable and dry season lengthening is already taking place, processes that lead to humidity reduction and favor fire spread on agriculture and forest lands (Coe et al, 2014, Davidson et al, 2012). The future ecologists and climatologists foreseen for Amazon is of increased exposure to uncontrolled fires, owing to major changes on forest structure (Nepstad et al, 2001, Malhi et al, 2008 Davidson et al 2012).

Accepting the premise that farmers seek to make the best decisions under the environmental and social constrains faced, it is consistent to state, in the basis of the evidences discussed, that the probability of losses from accidental fires is accounted for Amazonian farmers when making land management decisions.

This hypothesis, which is implicitly assumed in the literature, has not being submitted to a rigorous test. Such is contribution the paper aims at providing by relying on detailed survey data covering three municipalities of Pará state, Brazilian Amazon.

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 exposure to accidental fires to land allocation is also mentioned by Sorrensen (2004 p. 397), Mendonça et al (2004, p.90), Simmons et al (2004, p.92) and Arima et al (2007, p. 543).

In fact, some authors (Carvalho et al, 2002 and Nepstad et al, 2001, p.403) see on financial incentives to fire-susceptible land uses an instrument to reduce agricultural fire use, and, consequently, the risk of accidental fires (Barlow & Peres, 2004, p.11)[[2]](#footnote-2). Taking the reasoning further, by subsidizing the growing of perennials, for instance, policy makers would drive farmers to convert, to this land use, the land hitherto allocated to less sensitive uses, such as annual crops and extensive cattle ranching what, as a side-effect, would reduce the incentive to employ fire.

Notwithstanding, the probability of facing losses imposed by fires of external sources, i.e., neighboring farmers, will remain unaltered. It might just not pay-off to invest in perennials, after accounting for the losses, even when subsidies are available (Simmons et al, 2004).

On the other hand, if the probability of “external” accidental fires is systematically underestimated at a level the subsidy can compensate, the conversion of land to perennials will occur and the perceived vulnerability will consequently increase. However, exactly because farmers’ consider fire risk to be low, even negligible, the increase in perceived vulnerability would not necessarily be large enough to induce farmers to stop relying on fire-based land management.

The design of policies for controlling accidental fires has, therefore, to be based on an assessment of the probability farmers subjectively assign to these events. Is it of a magnitude large enough to affect the way land is managed?

This is the question the paper seeks to answer. For this, it relies on the theory and on the empirical method exposed on the next two sections. Section four presents the data. Results are analyzed in the fifth section and a brief conclusion follows.

Table 1 Data on fire use and accidental fires

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable measured** | **Indicator** | **Information** | **Source [reference year]** |
| Fire use rate | Farms with fire use / Farms | 30% in Brazilian Amazon, 14% in the whole country | IBGE [2006] |
| Firebreak rate | Households (HH) with firebreaks / households **[a] [b]** | 73% of 220 HHs | Bowman et al [2007] |
| Farmers with fire use and firebreaks / farmers with fire use | 90% of 355 farmers | RASDB [2010] |
| HHs with firebreaks /HHs **[c]** | 18% of 71 HHs on 2001, 53% of 53 HHs in 2006 | Souza [2001, 2006] |
| Probability of burnings turn into accidental fires | Farmers with uncontrolled forest fires / farmers with forest fires | 15% of 298 farmers | RASDB [2010] |
| Farmers with uncontrolled pasture fires / farmers with pasture fires | 9.5% of 72 farmers | RASDB [2010] |
| HHs with uncontrolled fires /HHs | 5.6% of 53 households | Souza [2006] |
| Probability of being victim of accidental fires | Farmers victim of uncontrolled fires started by neighbors /farmers | 28% of 488 farmers | RASDB [2010] |
| Farmers victim of uncontrolled fires started by themselves or by /farmers | 24% of 271 farmers | SHIFT [2001/2002] |

Notes: [a] Probably biased upwards owing to frequent visits from environmental authorities and NGOS (IBAMA, IPAM) to the protected area (surveillance of environmentally detrimental behavior). [b] HH stands for "households". [c] The 2006 ratio is probably biased upwards owing to a project, conducted by environmental authority and NGO (IBAMA and IPAM), aiming at promoting collective governance of fires.

Sources: IBGE (2010), Bowman et al (2008), "RASDB" stands for the paper's survey data (Gardner et al, 2013), Souza (2009), "SHIFT" stands for ZEF/EMBRAPA/NAEA (2002).

**2 Theory**

**2.1 Land use**

Following Just et al (1983), Chambers & Just (1986), Moore & Negri (1997), Feres et al (2009) and Pezzi & Bateman (2011), the problem of allocating, to J alternative land uses, an amount of farm land which is fixed in the short run, can be framed as follows.

Where Πj is the profit generated by the j-th land use, pi the output prices vector, r the input prices vector, aj the area allocated to the j-th land use and X, a vector of biophysical and socioeconomic factors that influence the magnitude of the profit obtained from the j-th land use. The total land available is denoted by A. The constraint can be written as a equality since the J land uses are an exhaustive list.

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):

Where all prices are specified in a common unit of value, a *numeráire*.

Fine scale spatial data and microdata are employed to estimate land use models generally by assuming that, at such scales, prices varies only with distances to input/output markets (Chomitz & Gray: 1996, Nelson & Geoghegan: 2002, Fezzi & Bateman, 2011).

Let the value received by the farmer as payment for the sale of one unit of product k (farmgate price) be given by pk = ‑ vkdk, where is the market price, vk the average transport cost by kilometer ($/unity/km) and dk, 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, . The price net of transport costs, however, varies with farmers’ location.

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 wr = + srdr, where is the price for which the input r is sold in the market, sr the average cost of transport by kilometer ($/unit/km) and dr, the distance between the farm and the market for input r.

Equation (1) can be adapted to microdata as follows.

Or, subsuming the average transport costs (vk’s and sr’s) to the coefficients, i.e., taking δkjvk = δ’kjand θrjsr = θ’rj, for all k and r:

On this last step, terms and were omitted since their values are fixed across farmers, making them meaningless for cross-sectional analysis.

**2.2 The fire exposure-land use channel**

As discussed in the introduction, the exposure to external (uncontrolled) sources of accidental fires is a reasonable factor to be considered among the components of vector X on (1’’). This section aims to detail a mechanism through which such factor exerts its influence on land use choice.

It is an intuitive hypothesis that the expected yield of a land use cannot be larger under exposure to external uncontrolled fires, controlling for other determinants of yield. Formally, this hypothesis can be stated, at parcel level, as:

E[yij| mij, ai, φi; fi = 0] ≥ E[yij| mij, ai, φi; fi = 1] (H1)

Where yij is the vector with the quantity of commodities generated from the j-th land use at the i-th parcel and mij, the vector with the cost minimizing amounts of all production factors, except for land. Parcel’s land area is ai and its biophysical characteristics are subsumed to φi. Whether j-th land use is exposed or not to accidental fires is indicated by the binary fi, with 1 in the affirmative case and 0 in the negative.

To show that H1 implies that profit cannot, as well, be larger, under accidental fire exposure, it is first necessary to define profit as:

πij = pyij – wmij – vai (D1)

Where p and w are, respectively, the price vectors for outputs and for production factors and v is the price of land.

The expected value of the profit yielded by the j-th land use when developed on the i-th land parcel is obtained by combining (H1) and (D1):

E[πij| mij, ai, φi, P; fi] = pE[yij| mij, ai, φi, P; fi] ‑ wmi,j ‑ vai (R1)

All prices are subsumed to vector P.

By applying H1 to R1, one has:

E[πij| mij, ai, φi, P; fi = 0] ≥ E[πij| mij, ai, φi, P; fi = 1] (R2)

Land use decision at the parcel level is generally modelled as a discrete choice between J land uses, where the land use with the highest profit is chosen (Nelson & Geoghegan: 2002). Under this approach, land uses on a state with non-negligible external fire exposure and on an exposure-free state differ only if the rank of land uses’ profits differ considerably between such states.

More precisely, two conditions must be verified for exposure to external fires to have land use implications. To state them, it is helpful to define the profit effect of external fire exposure (PEEFE) as δij = E[πij| mij, ai, φi, P; fi = 0] ‑ E[πij| mij, ai, φi, P; fi = 1].

First condition (C1) requires that PEEFE be not null for at least one land use; otherwise fire exposure would not have an effect on land use at all. Second condition (C2) is that at least two land uses must have distinct PEEFEs, since if all land uses’ profits differ on exposure and non-exposure states in the same magnitude, the states’ profit ranks cannot be distinct.

Conditions C1 and C2 are necessary conditions. Any evidence of an effect of fire exposure on land use is also a evidence that both conditions are verified. To seek for evidences of such kind is the goal of the empirical analysis. Its logic is detailed on figure 1.

The part of the mechanism on the interior of the dashed rectangle is not observable with the available data, remaining a black box. Only the effect of external fire exposure on land use areas, aggregated at the farm level, is observable. Based on the logical connection between the observable effect and conditions C1 and C2, it can be deducted, that, if the effect manifests, both conditions prevail. Contrariwise, consistent with the fact that C1 and C2 are necessary but not sufficient, nothing can be claimed.

**Figure 1 The logic of empirical analysis**



The relevance of empirical analysis has to be highlighted, since, under the validity of H1, evidence favorable to C1 implies that fire exposure reduces the economic return of land utilization, as proposition P1 states.

*Proposition P1: under H1, any evidence of an effect of external fire exposure on land use choice is an evidence that fire exposure reduces the profit yielded by land.*

The proof is stablished by the two facts below

(1) No land use can yield a larger profit on a state of higher exposure to external fires (this follows directly from R2);

(2) If a smaller aggregated area of a given land use, j', is observed under higher exposure, then there is at least one parcel, i', where (a) j' is not developed under higher exposure and (b) j' is developed under lower exposure. Under lower exposure then j'' ≠ j' is developed at i'. If j'' is available under higher exposure but not developed, it yields, under higher exposure, a smaller profit than j'. Additionally, by H1, the profit yielded by j'' cannot be higher under higher exposure. Then, the optimal allocation of i' under higher exposure, the land use j'', yields a smaller profit than its optimal allocation under lower exposure, j'.

**2.3 Rationale for biophysical and socioeconomic controls**

To keep consistency with the agricultural economics and land use literature, additional explanatory factors are considered as components of vector X, such as human capital (Just et al, 1983, Vosti & Witcover: 1996, Alix-Garcia et al: 2005 and Parman: 2012, p.17) and slope of farms’ terrain. The last affects land use decision through the cost of conducting cultivation procedures, especially when machines are employed (Robalino & Pfaff: 2011).

**3 Method**

**3.1 General model**

The goal of the analysis is to estimate E[aj| F, W], j=1,…,J, where aj is the area of the j-th land use, F is the degree of external fire exposure and W is the matrix of control variables with a first column of ones. The conditional expectation can be approximated by a linear form, E[aj| F, W] ≈ δF + Wβ. Consequently, the empirical model is:

aji = δjFi + wi’βj + uji, i=1,...,N, j=1,...,J (1)

Where i indicates the i-th farm in the cross-section, wi’ is the i-th row of W and uji is a zero-mean spherical random disturbance.

With this model, the hypothesis of no fire exposure effect on land use translates into H0: δj = 0, j=1,...,J.

**3.2 Econometric issues**

Two complications require the restatement of (1).

First, it is coherent with the models of land use choice that the land areas allocated to all J land uses result from the solution of the same choice problem where the allocation of the whole farm area is simultaneously determined (Fezzi & Bateman, 2011). Thus, Aj and As, ∀s≠j, are dependent and their respective linear equations of the form (1) have to be simultaneously estimated in order to avoid a suboptimal use of the available information contained on the data (Fezzi & Bateman, 2011, Moore & Negri, 1997). In particular, the existence of omitted factors that affect the area of more than one land use implies into correlation of disturbances across equations.

Furthermore, the areas dedicated to all land uses cannot be greater than the total farm area, A, i.e., . The number of degrees of freedom on the land use choice is thus J – 1, what means that only the area of J ‑ 1 land uses can be modelled since the area of the remaining land use does not result from choice but from the choice problem’s constraint.

Second, external fire exposure is endogenous owing both to the simultaneity of land use choice and fire use choice and to correlation with omitted factors.

Simultaneity occurs because fire sources in Brazilian Amazon are anthropic and, on the rural areas focused on the paper, consist overall on fire-based land management (Aragão & Shimabukuro, 2010, Carmenta et al, 2011). From the strictly individual standpoint a farmer has no incentive for taking into account the risk his/her fire use imposes to other farmers’ land uses. But the farmers that face the risk of accidental fires generated by their neighbors do have incentive for intervening on neighbors’ fire use decision. It is intuitive that the incentive grows with the economic value (latent profit) of the land uses at stake (Cabrales et al, 2003, Shafran, 2008, Bowman et al, 2008). As the classical model of Coase (1960) suggest, the private intervention on socially detrimental private decisions tend to be successful when the stakeholders can costlessly bargain. Then, the fire sources, their position on space and, more generally, the extent of the “social” threat they represent, might be correlated with the way in which proximate farms are allocated to alternative land uses.

Omitted variable bias might arise from local unobserved factors which drive land use and fire use decisions.

One model which allows for consistent estimation under the two complications detailed is the SUR-IV below (Barbosa et al: 2012).

a1i = δ1Fi + wi’β1 + u1i, i=1,...,N

a2i = δ2Fi + wi’β2 + u2i, i=1,...,N

...

aJ-1i = δJFi + wi’βJ + uJi, i=1,...,N

Fi = zi’ρ + wi’γ + ϵi

The last equation is the reduced form equation for the endogenous external fire exposure (F), where zi’ is the vector of available instruments.

The full system can be estimated by three stage least squares (3SLS) and by the generalized method of moments (GMM). The results of both techniques are considered.

A third econometric issue is corner solution for land use areas (Fezzi & Bateman, 2011, Moore & Negri, 1997). Not all land uses are developed on every farm. To obtain consistent point estimations for the coefficients equation-by-equation IV-tobit is pursued, a method which is, nevertheless, inefficient, since it does not incorporate the possibility of cross-correlation between equations’ disturbances.

**3.3 Rationale for IV**

For a land cover removal to be successful through fire it cannot be started on the rainy season. Yet, for preventing the burn to run out of control, the driest days of the year must be avoided. The optimal timing is such that fire is not extinguished by the rain and also do not cause losses to the fire starter and to society (Sombroek, 2001, Sorrensen: 2004, Carvalheiro: 2006, Souza: 2009, Bowman et al: 2008, Righi et al: 2009). Conclusively, precipitation is a driver of fires detected on Amazon, since it affects the pay-off of agricultural burnings.

It follows that a metric of precipitation on the area near farms’ boundaries is a potentially valid instrumental variable for exposure to external fires. The exclusion restriction is verified only if the precipitation metric does not directly explains (causes) the dependent variables, farmers’ own land-use areas. This seems to be the case of the volatility, across time, of the annual number of dry days at farms’ neighborhoods. Farmers might know, and account for, the (seasonal) precipitation regime that prevails inside their farms, synthesized by the annual number of days without rain, i.e., dry days. It is less likely that they know and account for the regime which prevails on the neighborhood of their farms.

Exogeneity is also verified by external precipitation regime since there is no clear unobserved factor to which it is correlated to and which is also correlated with land use decision.

In basis of this argument, two instrumental variables are incorporated, the average number of dry days of 2008 within buffers on 2km of farms’ boundaries and the annual volatility of dry days from 2005 to 2008 on these surrounding areas. Volatility of precipitation regime captures the degree of uncertainty faced by farmers while making their fire use choices.

The year of 2008 is chosen since it corresponds to the information available to farmers when choosing the land use areas observed on the data, which refer to 2009.

**4 Data**

Two are the data sources accessed. First, a farm-scale socioeconomic survey conducted on the municipalites Paragominas, Santarém and Belterra, Pará state, Brazilian Amazon, during 2010 and 2011 by Rede Amazônia Sustentável (RAS), an international research network (for details, the reader is referred to Gardner et al, 2013). Second, georreferenced data collected from multiple secondary sources, such as NASA’s website. The connection of the two data sources was made possible by the digitalization of the boundaries of the farms surveyed.

**4.1 Fire and precipitation data**

The degree of fire exposure is proxied by the total number of thermal anomalies, or simply, “fires”, detected by satellite on a buffer of 2 km of farm borders. Detections come from MODIS sensor images processed by NASA and made available through the Fire Information for Resource Management Systems (FIRMS)[[3]](#footnote-3). According with observations of accidental fires registered in the literature 2 kilometers is a reasonable radius of spread (see, for instance, Mendonça et al., 2004, Alencar et al., 2006, Nepstad et al., 1999 and Cochrane, 2009, chapters 1 and 14).

It is built, from the number of fires detected within farms’ boundaries, an explanatory binary with unitary level for the farms with a positive count. The data source is also NASA FIRMS. The number of fires detected within farms’ boundaries, hereafter internal fires, it a control for the use of fire by farmers. Sensitiveness to external fire exposure might differ between farmers that use fire and those that do not[[4]](#footnote-4). This control allows for capturing this effect.

Precipitation data, on a millimeters per day basis, is available on NASA’s Tropical Rainfall Measuring Mission, Giovanni data collection platform[[5]](#footnote-5). For each year of the period 2005 to 2008, the number of dry days, i.e., days with null precipitation, were counted and the standard deviation (across time) for each of the 0.25° x 0.25° cells (28.5 x 28.5 km) covering the study regions were calculated. Farms’ buffers generally overlapped more than one cell of the TRMM grid. To compute the value of the metric for the whole buffer, the standard deviations of each overlapping cell was weighted by the share of buffers’ area overlapped[[6]](#footnote-6).

**4.2 Market proximity metrics**

The available data allows the generation metrics that may capture the effect of locational factors which affect more than one land use. 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.

4.2.1 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 2 summarizes the main information for the purposes here envisaged.

**Table 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 neither cattle nor 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[[7]](#footnote-7). 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.

This identification approach 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).

4.2.2 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, in Portuguese) 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.

4.2.3 Travel time to urban centers

Farmers reported the amount of time spent to arrive at the nearest 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 Further controls**

Farmers’ human capital is proxied by an educational level dummy which assumes unitary value for farms where the person that answered the survey questions regarding land use and production (the decision maker, supposedly) 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).

Farms’ average slope is calculated from a Digital Elevation Model with 30m resolution, resampled to 100m resolution.

A dummy variable is included in order to capture peculiarities of the two regions, (i) Paragominas, and (ii) the contiguous municipalities of Santarém and Belterra, which are not controlled by other factors.

**4.4 Survey and sample**

Lack of availability or soundness of information required the exclusion of some surveyed farms from the estimation sample. An account of excluded farms and exclusion criteria is given on table 3.

**Table 3 Account of farms excluded from sample**

|  |  |  |
| --- | --- | --- |
| **Reason for exclusion** | **count** | **percent** |
| Lack of sound information to digitalize farm boundaries | 15 | 9% |
| Lack of sound information to link multiple farm polygons with survey data | 19 | 11% |
| Null crop and pasture areas | 21 | 12% |
| Missing dependent variable or covariates | 17 | 10% |
| Land use areas outliers | 74 | 44% |
| Mixes of the three last criteria | 24 | 14% |
| **Total number of farms excluded** | **170** | |
| **Total number of farms surveyed** | **487** | |
| **Farms remaining on sample** | **317** | |

The first two criteria on the table are related with the possibility of connecting ground survey with satellite data. For 34 farms there is no reliable information on farm boundaries or there is a lack of clearness on the relation of the answers provided with multiple landholdings digitalized. The last caveat is not an issue for the dominant case where only one landholding was declared by farmers.

Farms with null crop and pasture areas on 2009 are excluded since these are the main economic activities developed on the rural regions of the municipalities covered. None of the 21 producers excluded solely in the basis of such criteria informed a non-null production from other land uses besides crop and cattle ranching, accounting for forest plantations, logging and non-timber forest products collection.

Outliers are defined as observations with values above the 90 percentile for areas of each of the three land uses modelled. What corresponds to 14.7 ha, 80 ha and 186.1 ha for crop, pasture and forest land, respectively. Farms above at least one of these three thresholds are ignored.

The exclusion of land use areas outliers aims to focus analysis on the group of farmers which the data captures best. As table 4 shows, the sample is dominated by areas below 100 hectares for the three land uses considered and also for the whole farm area.

**Table 4 Observation by area classes (hectares), sample with area outliers**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Class** | **Crop** | | **Pasture** | | **Forest** | | **Whole farm** | |
| area = 0 | 54 | 14% | 189 | 48% | 24 | 6% | 0 | NA |
| 0 < area ≤ 10 | 292 | 75% | 80 | 20% | 112 | 29% | 86 | 22% |
| 10 < area ≤ 100 | 21 | 5% | 86 | 22% | 203 | 52% | 227 | 58% |
| 100 < area ≤ 1,000 | 23 | 6% | 28 | 7% | 39 | 10% | 52 | 13% |
| area > 1,000 | 1 | 0% | 8 | 2% | 13 | 3% | 26 | 7% |
| Total | 391 | 100% | 391 | 100% | 391 | 100% | 391 | 100% |

The frequency distribution of crop area is heavily left-skewed, with 326 of 391 observations (83%) with less than 5 hectares. There are also 24 of 391 observations (6%) with more than 100 hectares. The sample captures two highly distinct groups, smallholders engaged on labor-intensive staple crop production and large scale soybean producers that rely on capital-intensive technologies. The former group is over-represented, dominating the sample, while the latter is under-represented with only 26 soybean growers among 391 farmers (7%). Medium to large crop growers are captured only as outliers. The sharp differences between the two groups create discrete variations on the data, leading to non-gaussian features that econometric models cannot deal with.

The over-representation of smallholders and the under-representation of medium to large holders is a sample’s feature that must be highlighted owing to the severity of its implications on the quality of econometric results.

The empirical distribution of pasture area provided further corroboration, since it is also heavily left-skewed with 92% of the sample below 5 hectares, 48% with null pasture area and 43% with a positive area below 5 hectares. A group of large scale cattle ranchers with more than 500 hectares of pasture is also included, with 20 farmers out of 391 (5%).

The sample captures sharp distinctions that lead to discrete variability or discontinuities on variables’ distributions. Point estimates of almost all coefficients are individually not significant when area outliers are included, since these areas, which are the variables to be explained, are far from being normally distributed.

**4.5 Model variables**

Areas allocated for three land uses are modelled, crops, pasture and forest (primary and secondary). Land uses developed by the minority of the sampled farmers, such as forest plantations, agroforestry, garden and other are summed up into a single residual land use class and left out of modelling. Variables definitions and statistical summary are provided, respectively, by tables 5 and 6 below (after the conclusion).

**5 Results**

Exposure to fires coming from the outside has a negative influence on pasture area and a positive influence on forest area, according to GMM IV and Bootstrapped IV-SUR (3SLS) if a 10% significance level is tolerated (tables 7 and 8).

This evidence has to be interpreted under the light of the mechanism detailed on section two. Thus proceeding, it can be stated that the practice of burning land cover exerts, through the externality of external fires, influence on land use decisions.

If it is accepted that there is no land use whose expected yield is larger under fire exposure (H1), then, as proposition 1 stablishes, there is evidence that the exposure to external fires causes the reduction of the economic return provided by the land available on the study regions.

All affirmations above are, of course, valid only to the conditions captured by the data, being restricted to the municipalities covered and for the year of 2009, the reference for the land use data.

The rise of exposure in one additional fire detection leads to a pasture area reduction approximately equivalent to the expansion on forest area. The difference of the absolute values the coefficient takes on pasture and forest equations, is of one hectare, at maximum, along models. This is consistent with the assumption of fixed farm area.

Point estimations from GMM show that the increase in external fire exposure in one additional fire source drives farmers to decrease their pastures in 6.2 hectares and to increase forestland in 7.3 hectares.

The validity of instrumental variables is not rejected by the overidentification test performed after IV-SUR estimations, attesting the successfulness of the identification strategy. Nevertheless, exogeneity of external fire exposure is not rejected on Wald tests performed after IV-tobit, except for the forest equation and if a 10% significance level is tolerated.

Models are not successful in explaining crop area. No covariate proves to be a significant predictor, except on IV-SUR results. One reason might be the multiple discontinuity of crop area (table 11). Another, the fact that it incorporates perennials, which tend to be not well described by short-term models based on snapshot values for covariates, especially prices, as it is the case here (Knapp: 1987).

To verify whether discontinuity is making point estimates and inference imprecise for the crop area, the equation was separately estimated with a multinomial logit. The dependent variable is a discrete variable with ten values, or “options”, indicating discontinuity points or intervals in between, according with the first row of table 10. Estimation statistics for significant covariates are presented on table 11, except for total area, which were significant for all values of the dependent variable, except one.

**6 Conclusion**

Anthropic fire sources on the vicinity of farms are potential threats for agriculture, forestry and sustainable forest management. Activities' expected profits tend to fall when the invasion of farm by fires from the outside becomes more probable. The number of fires set by neighbors is one of the factors driving such probability.

According with the results, such factor has a significant influence on land use choices made by smallholders located on Paragominas and Santarém municipalities. Then, according with the external fire-land use mechanism described, it can be concluded that fire exposure diminishes economic return of land use with detrimental effect on cattle ranching.

Additionally, it is attested that the mere probability of accidental fires tends to influence land use decisions even if accidental fires do not effectively occur.

Precipitation proves to be a valid source of exogenous variation for identifying the effect of fire exposure.

The paper relies on farm-level survey which is more detailed and able to capture the recent changes on Brazilian Amazon, compared with the latest Agriculture Census of 2006. The drawbacks are the limited spatial coverage (as detailed in Gardner et al: 2013) and also the under-representation of medium to large holders and the over-representation of smallholders. Ground survey data is connected with satellite data on precipitation, slope and on the location of roads, municipal capitals, cattle slaughterhouses and ports.

Since fire users do not internalize the threat they impose to neighboring farmers, fire use might be above the socially optimal level and the area allocated to some land uses bellow the socially optimal level. The policy implication of the paper is, thus, that effective alternatives for internalizing fire risk must be created. Ongoing climate change increases the need for effective progress in such direction.

**Table 5 Definition of variables**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **N** | **Description** | **Short name** | **Measure for...** | **Unit** |
| **0** | Area allocated to crops | Crop area | Land use decision (dependent variable) | hectares |
| **0** | Area allocated to pasture | Pasture area | Land use decision (dependent variable) | hectares |
| **0** | Area allocated to forest | Forest area | Land use decision (dependent variable) | hectares |
| **1** | Count of fire detections on 2km buffers from farm boundaries | External fire exposure | External fire exposure | count |
| **2** | Distance to the nearest state or national road | Distance to roads | Distance to local and national markets | kilometers |
| **3** | Distance to the nearest municipal capital | Distance to urban centers | Distance to local markets | kilometers |
| **4** | Distance to the nearest (cattle) slaughterhouse | Distance to slaughterhouses | Distance to local and national markets | kilometers |
| **5** | Distance to the nearest port from which timber is exported | Distance to timber ports | Distance to international market | kilometers |
| **6** | Distance to the nearest port from which soybean is exported | Distance to soybean ports | Distance to international market | kilometers |
| **7** | Time taken to arrive at the nearest urban center (as reported by interviewees) | Travel time to urban centers | Distance to local markets | minutes |
| **8** | Slope of the terrain | Slope | Production cost | percentage (100%) |
| **9** | Total area of the farm | Total area | Scale economies on farming | Hectares |
| **10** | Internal fire detection dummy ( = 1 if hotspots have being detected within farm, 0 otherwise) | Internal fires | Sensitivity to fires | binary |
| **11** | Education dummy ( = 1 if the farmer has education above the lower secondary, 0 otherwise) | Education | Human capital | binary |
| **12** | Region dummy (1 for Paragominas, 0 for Santarém-Belterra) | Region | Regions' peculiarities | binary |
| **13** | Number of days without rain on 2km buffers from farm boundaries | External Dry days | Fire use determinants(instrumental variable) | count |
| **14** | Volatility of the annual number of days without rain on 2km buffers from farm boundaries (2005-2008) | External precipitation regime volatility | Fire use determinants (instrumental variable) | count |

**Table 6 Statistical summary**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **N** | **Mean** | **Standard deviation** | **Minimun** | **Maximum** |
| Crop area | 317 | 1.93 | 2.21 | 0 | 14.70 |
| Pasture area | 317 | 8.61 | 16.47 | 0 | 80.00 |
| Forest area | 317 | 28.46 | 30.93 | 0 | 132.40 |
| External fire exposure | 317 | 2.14 | 2.67 | 0 | 15.00 |
| Distance to roads | 317 | 5.49 | 6.71 | 0 | 27.83 |
| Distance to urban centers | 317 | 34.98 | 18.89 | 4.14 | 72.03 |
| Distance to slaughterhouses | 317 | 67.40 | 46.47 | 10.11 | 169.02 |
| Distance to timber ports | 317 | 92.19 | 83.36 | 8.50 | 256.21 |
| Distance to soybean ports | 317 | 122.90 | 134.08 | 8.50 | 434.62 |
| Travel time to urban centers | 317 | 103.38 | 66.12 | 2.00 | 300.00 |
| Slope | 317 | 4.23 | 2.63 | 0 | 23.83 |
| Total area | 317 | 41.16 | 39.41 | 0.66 | 200.00 |
| Internal fires | 317 | 0.04 | 0.21 | 0 | 1 |
| Education | 317 | 0.08 | 0.27 | 0 | 1 |
| Region | 317 | 0.27 | 0.45 | 0 | 1 |
| External Dry days | 317 | 199.89 | 17.30 | 166.68 | 223.00 |
| External precipitation regime volatility | 317 | 10.70 | 2.20 | 6.07 | 19.50 |

**Table 7 SUR IV estimation results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Crop area** | | **Pasture area** | | **Forest area** | |
| **Variables** | **SUR IV** | **Boot** | **SUR IV** | **Boot** | **SUR IV** | **Boot** |
| External fire exposure | 0.464 | 0.464 | -6.055\* | -6.055+ | 6.678\* | 6.678+ |
|  | (0.429) | (0.438) | (2.869) | (3.311) | (3.048) | (3.945) |
| Distance to roads | -0.034 | -0.034 | 0.959\* | 0.959+ | -1.078\* | -1.078+ |
|  | (0.066) | (0.072) | (0.444) | (0.509) | (0.472) | (0.595) |
| Distance to urban centers | -0.014 | -0.014 | 0.050 | 0.050 | -0.029 | -0.029 |
|  | (0.016) | (0.018) | (0.106) | (0.117) | (0.113) | (0.125) |
| Distance to slaughterhouses | -0.005 | -0.005 | -0.134\* | -0.134\* | 0.121+ | 0.121+ |
|  | (0.010) | (0.011) | (0.064) | (0.068) | (0.068) | (0.070) |
| Distance to timber ports | 0.005 | 0.005 | 0.083 | 0.083 | -0.089 | -0.089 |
|  | (0.008) | (0.011) | (0.056) | (0.060) | (0.060) | (0.065) |
| Distance to soybean ports | 0.010 | 0.010 | -0.206\*\* | -0.206\*\* | 0.212\*\* | 0.212\* |
|  | (0.009) | (0.009) | (0.063) | (0.072) | (0.067) | (0.089) |
| Travel time to urban centers | -0.003 | -0.003 | -0.051\* | -0.051 | 0.061\* | 0.061+ |
|  | (0.004) | (0.005) | (0.026) | (0.035) | (0.027) | (0.034) |
| Slope | 0.019 | 0.019 | -0.257 | -0.257 | 0.547 | 0.547 |
|  | (0.060) | (0.054) | (0.399) | (0.295) | (0.424) | (0.352) |
| Total area | 0.006 | 0.006 | 0.383\*\*\* | 0.383\*\*\* | 0.516\*\*\* | 0.516\*\*\* |
|  | (0.007) | (0.007) | (0.048) | (0.071) | (0.052) | (0.071) |
| Internal fires | -0.692 | -0.692 | 2.858 | 2.858 | 0.737 | 0.737 |
|  | (0.672) | (0.557) | (4.496) | (4.362) | (4.778) | (4.978) |
| Education | -0.465 | -0.465 | 2.909 | 2.909 | -4.266 | -4.266 |
|  | (0.571) | (0.512) | (3.821) | (4.618) | (4.060) | (5.523) |
| Region | -3.586 | -3.586 | 72.333\*\* | 72.333\*\* | -72.429\*\* | -72.429\* |
|  | (3.707) | (3.408) | (24.816) | (26.394) | (26.367) | (33.100) |
| \_cons | 1.355\*\* | 1.355\*\* | 11.927\*\*\* | 11.927\*\* | -14.790\*\*\* | -14.790\*\* |
|  | (0.523) | (0.444) | (3.499) | (3.998) | (3.718) | (4.931) |
| N | 317 | 317 | 317 | 317 | 317 | 317 |
| R2 | -0.066 | -0.066 | 0.144 | 0.144 | 0.726 | 0.726 |
| Joint significance (p-value) | 0.021 | 0.021 | 0.000 | 0.000 | 0.000 | 0.000 |

Note: “Boot” stands for Bootstrapped SUR-IV (3SLS). Bresch-Pagan test of cross-equation independence of residuals rejects the null at 0.1% level. Overidentification test does not reject the null of instruments validity (p-value of the test is 0.62).

**Table 8 IV Tobit and GMM estimation results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Crop area** | | **Pasture area** | | **Forest area** | |
| **Variables** | **Tobit** | **GMM** | **Tobit** | **GMM** | **Tobit** | **GMM** |
| External fire exposure | 0.576 | 0.465 | -7.368 | -7.137\* | 7.420+ | 6.209+ |
|  | (0.532) | (0.465) | (4.766) | (3.382) | (3.930) | (3.259) |
| Distance to roads | -0.036 | -0.032 | 1.119 | 1.113\* | -1.170+ | -1.050\* |
|  | (0.080) | (0.071) | (0.718) | (0.536) | (0.597) | (0.506) |
| Distance to urban centers | -0.016 | -0.012 | 0.082 | 0.070 | -0.021 | -0.025 |
|  | (0.022) | (0.020) | (0.173) | (0.127) | (0.136) | (0.122) |
| Distance to slaughterhouses | -0.006 | -0.005 | -0.204\* | -0.118 | 0.103 | 0.134+ |
|  | (0.013) | (0.012) | (0.103) | (0.077) | (0.086) | (0.072) |
| Distance to timber ports | 0.005 | 0.004 | 0.220\* | 0.071 | -0.092 | -0.093 |
|  | (0.012) | (0.011) | (0.088) | (0.070) | (0.077) | (0.066) |
| Distance to ports | 0.014 | 0.010 | -0.332\*\* | -0.233\*\*\* | 0.222\*\* | 0.206\*\* |
|  | (0.010) | (0.009) | (0.101) | (0.070) | (0.081) | (0.070) |
| Travel time to urban centers | -0.003 | -0.003 | -0.067 | -0.057 | 0.070+ | 0.058+ |
|  | (0.005) | (0.005) | (0.050) | (0.036) | (0.038) | (0.033) |
| Slope | 0.020 | 0.017 | 0.157 | -0.256 | 0.628 | 0.507 |
|  | (0.056) | (0.050) | (0.584) | (0.392) | (0.426) | (0.371) |
| Total area | 0.002 | 0.006 | 0.544\*\*\* | 0.416\*\*\* | 0.514\*\*\* | 0.531\*\*\* |
|  | (0.009) | (0.007) | (0.095) | (0.067) | (0.073) | (0.063) |
| Internal fires | -0.731 | -0.708 | 2.903 | 2.880 | 0.483 | 0.387 |
|  | (0.645) | (0.545) | (6.005) | (5.436) | (5.673) | (5.053) |
| Education | -0.682 | -0.424 | 3.355 | 1.849 | -5.006 | -5.334 |
|  | (0.659) | (0.541) | (6.033) | (4.254) | (4.974) | (4.340) |
| Region | -5.170 | -3.582 | 95.353\* | 82.232\*\* | -75.372\* | -70.513\* |
|  | (4.114) | (3.617) | (38.067) | (27.595) | (32.766) | (28.561) |
| \_cons | 1.157\* | 1.317\*\* | -2.433 | 12.853\*\* | -16.883\*\*\* | -14.285\*\*\* |
|  | (0.521) | (0.436) | (5.647) | (3.950) | (4.651) | (4.035) |
| N | 317 | 317 | 317 | 317 | 317 | 317 |
| p-value exogeneity test | 0.323 | NA | 0.156 | NA | 0.091 | NA |

**Table 9 Discontinuity points\* of the empirical distributions of dependent variables**

|  |  |  |
| --- | --- | --- |
| **Land use** | **Count** | **Values** |
| Crop | 5 | 0 [9%], 0,6[9%], 0,9[8%], 1[8%], 1.5[6%] |
| Pasture | 1 | 0 [52%] |
| Forest | 1 | 0 [6%] |

Note: relative frequencies in brackets.

\*values with relative frequencies above 5%

**Table 10 Multinomial logit selected results, crop equation**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Covariates / choice** | **1 < crop <1.5 ha vs null crop area** | **0 < crop < 0.6 ha vs null crop area** | **0.6 ha vs null crop area** | **1 ha vs null crop area** | **crop > 1.5 ha vs null crop area** |
| External fire exposuse | 0.319+ | NS | NS | NS | NS |
|  | (0.193) |  |  |  |  |
| Distance to soybean ports | NS | NS | 0.048\* | 0.048\* | 0.032\* |
|  |  |  | (0.021) | (0.02) | (0.18) |
| Travel time to urban centers | NS | 0.012+ | NS | NS | NS |
|  |  | (0.07) |  |  |  |
| Education | NS | NS | -1.663+ | NS | -1.307+ |
|  |  |  | (0.923) |  | (0.74) |
| Region | NS | NS | -8.313+ | NS | NS |
|  |  |  | (-4.703) |  |  |

Note: “NS” stands for not significant (p-value > 0.1). Total area was omitted since it is significant for nine of the ten options.

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1. What respondents meant by firebreaks is not clear on the surveys. According with Carvalheiro (2009), "[surveyed Amazonian smallholders] refer to a simple border between the slashed vegetation and the standing forest as a 'firebreak', not considering whether or not the vegetation spread along this area has been removed." Additionally, as the same author rightly states, firebreaks are no guarantee of protection against fire spreads. They act to block uncontrolled fires to spread being, thus, not a measure to keep control of fires. Souza (2009), also surveying FLONA Tapajós households, found that 83% of the 53 households “recognized that there was still a risk of accidental fires” even being that 53% of them built firebreaks. [↑](#footnote-ref-1)
2. 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.” [↑](#footnote-ref-2)
3. <https://earthdata.nasa.gov/data/near-real-time-data/firms>, series selected was “Near Real-Time (NRT) MODIS Thermal Anomalies / Fire locations processed by NASA FIRMS” (delivered by e-mail). [↑](#footnote-ref-3)
4. Of course, farmers might differ in terms of their options by fire use and still do not differ in terms of the subjective probabilities they impute to accidental fire spread since the options in question are driven by other factors such as the cost of the available land cover conversion techniques. [↑](#footnote-ref-4)
5. <http://disc.sci.gsfc.nasa.gov/giovanni>, series selected was “3B42 V7 derived”, daily precipitation. [↑](#footnote-ref-5)
6. Georreferenced data manipulation was developed with softwares ArcGIS 10 ® and R (http://cran.r-project.org/). [↑](#footnote-ref-6)
7. 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). [↑](#footnote-ref-7)