Agricultural use of fire in the Brazilian Amazon: assessing the role of farms' boundaries

Thiago Fonseca-Morello

Universidade Federal do ABC (UFABC), Centro de Engenharia, Modelagem e Ciências Sociais Aplicadas (CECS)

Rua Acturus s/n, 09606-070, Jardim Antares São Bernardo do Campo, SP, Brasil

{fonseca.morello}@ufabc.edu.br

Abstract. This paper conducts an econometric analysis of MODIS fire detections whose basis is the economic theory of externalities. Data comprises, additionally, land property information from the Rural-Environmental Land Registry (CAR) and land use, with the municipality of Paragominas being the study region. The main goal is to refute the hypothesis that, controlling for land profitability, Amazonian farmers tend to burn closer to farms' boundaries, transferring to society a relevant fraction of the damage imposed by eventual escaped fires. To account for the uncertainty regarding effective fires' location a metric for the probability of fire location is proposed and taken as the explained variable. The partially discontinuous behavior of this variable is modelled with Tobit and Probit non-linear regression models. The results demonstrate that farm boundaries are statistically significant predictors of fire detections, after accounting for the influence of proxies for the economic value of land, including the value at risk of being accidentally burned. Farmers of Paragominas tend to burn closer to boundaries, not fully internalizing the cost of fire use. The regime of complete internalization, established by the controlled burn law, does not seem to be enforced in practice. The main implication for future research is the attested relevance of land property as a predictor of fire detections. The knowledge accumulated up to the present time comes, overall, from statistical models that account only for biophysical and/or geographical predictors, overlooking the role of property rights.

Palavras-chave: agricultural fires, externalities, econometrics, neighborhood effect; queimadas, externalidades, econometria, efeito de vizinhança.

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 through 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, “pasture fire”, 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, 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). Vegetation can be removed manually using an axe or chainsaw or with equipment, i.e. tractors. Fertilization of soil can be achieved using organic and/or chemical treatments and weeds can be managed both manually and with herbicides. Nevertheless these non-fire alternatives are more demanding in terms of both financial and human capital; they tend to be, in the short term, less economically rewarding.

However, short-term cost-benefit can be, at least partially, compensated by the risk of damaging crops, pasture, fences, infrastructure and machinery (Mendonça et al. 2004, Bowman et al. 2008) when the fire goes out of control, spreading beyond the targeted location. Of course, this depends on the fraction of the total expected damaged borne by the farmer at the fire’s source. The smaller the fraction, i.e., the larger the fraction transferred for neighbors and society as a whole, the less relevant for farmers is, in practice, the risk of accidental fires. But how relevant is the socialization of accidental fire risk, currently, in Brazilian Amazon?

To answer this question, the paper aims to test the hypothesis that farmers select parcels for treating with fire accounting not only for the economic return of the operation, but also for how distance parcels are from farms boundaries, which are “natural” thresholds for risk internalization.

The analysis is based upon geo-referenced 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.

2.Method

2.1 Theory

That accidental fires can induce several damages is sufficiently stressed in the literature. 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 (Morello, 2013, chapter 3).

Between two parcels whose profit generating potential differ only negligibly and which are also surrounded by parcels only slightly different in their economic potential, the parcel closer to farm boundaries is the best option for being treated with fire, from the strict standpoint of the individual farmer. The reason is clear: if a farmer has to compensate only partially his/her neighbors for damages caused by fires s/he started, boundary parcels are always more attractive - depending, of course, on their profitability.

2.2 Econometric approach

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, thereby obtaining two classes of “polygonal locations”: (i) interior-perfectly-squared-shaped-polygons and; (ii) border-polygons whose shape is molded, overall, by the outline of the farm boundary. Pieces of land belonging to these two classes are, in what follows, referred as “land parcels,” or, synthetically, as “parcels.”

As proposed in 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:

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

where $\Pi(LC_i)$ is the economic return of the land conversion, $E(L_i)$, is the expected monetary value of losses caused by accidental fires and d_int a binary variable indicating with unitary value if the parcel is an interior polygon, being, thus, located more than 1km away from the farm boundaries, and with zero if not.

The economic return of land conversion, or the potential-effective profit differential, is proxied by parcel’s slope, its distance to roads, total area and the amount of its area allocated to crops, pasture or silviculture (to be referred as “CPS” area), which are the main income-generating activities of rural properties of the study region.

The general structure of the econometric model is

$$P(y=1|Z, d\_int) = \Phi(\beta + \Gamma Z + \delta d\_int) \quad (2)$$

where $P(y_i=1|z_1)$ is the probability of parcel “i” to be treated with fire and Z the vector of control variables and Φ is the standard normal cdf.

2.3 Data and variables

Hotpixel data were collected from MODIS Active Fire & Burned Area Products website (http://modis-fire.umd.edu/index.html), only for the year of 2010, in order to match the period of the land use map.

Owing to the 1km resolution of the data, the effective fire source can be located anywhere within the radius of 1km from the reported fire detection. The actual location can thus be conceived as being randomly distributed with equal probability along a circular 1km-radius buffer centered in the reported location. The share of the buffer’s area which overlaps a land parcel is a metric for the probability of the detected fire to have taken place in the parcel. Since multiple fire-detection-centered buffers can overlap a parcel, the maximum size of overlapping, measured as the share of the buffers’ total area, is taken as the final metric for the probability of a parcel being treated with fire.

The database of the Rural Environmental Registry (“RER” or “CAR,” in Portuguese) contained, up to April 2010, information on 83% of the municipality’s rural property area.

To define parcels, the property polygons were partially subdivided by overlapping the map with their boundaries with a grid of 1 km x 1 km. The huge size of properties guarantees that fragments smaller than the whole are obtained for all properties. This is demonstrated by the numbers in Table 1, with statistics for total farm area and number of parcels.

Table 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

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

TerraClass 2010 is the information source for land use. Description of the classes and methodology can be found in INPE (2011 and 2013a). 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.), thus being ineligible for studying the choice of land conversion technique (fire or not).

Table 2 lists the empirical model variables and their statistical summary is found on Table 3.

Table 2 Variables of the model

N	Description	Short name	Measure for...	Unit
0	Probability of fire detection	Fire prob	Dependent variable	percent
0	Fire detection?	Fire dummy	Dependent variable	binary
1	Parcel's crop, pasture and silviculture (CPS) area	Parcel's CPS area	Potential-effective rent differential	hectares
2	Slope of the terrain	Slope	Potential-effective rent differential	percent
3	Distance to roads	Income	Potential-effective rent differential	km
4	Own CPS area within 2km	Own CPS within 2km	Expected loss from scaped fires	hectares
5	Second party CPS area within 2km	2nd party CPS within 2km	Expected loss from scaped fires	hectares
6	Parcel's total area	Parcel's area	Control for area heterogeneity	hectares
7	Internal parcel?	Internal parcel?	Internalization of scaped fires	binary

Note: variables indicated with number zero are explained or dependent variables, the remaining being explanatory.

Table 3 Statistical summary of variables

Variable	N	Mean	Standard deviation	Minimun	Maximum
Fire prob	18770	0,01	0,06	0	1
Fire dummy	18770	0,12	0,33	0	1
Parcel's CPS area	18770	18,33	28,61	0	100,00
Slope	18770	4,52	2,82	0,53	27,52
Income	18770	11,68	8,88	0	40,36
Own CPS within 2km	18770	167,19	192,70	0	1068,84
2nd party CPS within 2km	18770	164,63	194,89	0	1219,51
Parcel's area	18770	60,60	36,03	1,00	100,00
Internal parcel?	18770	0,28	0,45	0	1

3.Results and brief discussion

Results on table 4 do not refute the hypothesis of externalization of damages from scaped fires. After controlling for proxies for the potential-effective land rent differential and also for the value of asset at risk within 2km, the fact of a parcel being internal (or not) to the farm still have a statistically significant contribution for explaining the sample variation of the probability of fire detection. Such contribution manifests as a negative influence, i.e., internal parcels (which are at least 1km away from farms' border) have a smaller probability of being treated with fire, conditional on the incentive to convert parcel's land and on the expected loss caused by an eventual loss of control of the fire.

A willingness to burn close to farm boundaries, socializing uncertain but probable damages from accidental fires is, thus, evidenced by the results.

Both regressions are globally significant as attested by the Chi-squared and F tests.

Table 4 Estimation results

Variables	Probit, explained: fire dummy	Tobit, explained: fire prob
Parcel's CPS area	0.013***	0.003***
	(0.001)	(0.000)
Slope	-0.005	-0.002*
	(0.004)	(0.001)
Income	-0.009***	-0.002***
	(0.001)	(0.000)
Own CPS within 2km	-0.001***	-0.000***
	(0.000)	(0.000)
2nd party CPS within 2km	-0.000	-0.000
	(0.000)	(0.000)
Parcel's area	-0.002**	-0.000***
	(0.000)	(0.000)
Internal parcel?	-0.079*	-0.017*
	(0.035)	(0.007)
intercept	-1.004***	-0.186***
	(0.042)	(0.010)
sigma		
intercept		0.206***
		(0.006)
Observations	18770	18770
Pseudo R^2	0.041	0.069
Log-likelihood	-6623.567	-4015.486
Chi-squared global significance test (statistic)	541.606	
F global significance test (statistic)		67.246

Note: Standard errors in parentheses and point estimates for parameters (β, Γ and δ, equation 2 above). Significance levels are denoted by: + p<0.10 (significant at 10%), * p<0.05 (significant at 5%), ** p<0.01, *** p<0.001.

4.Conclusion

The estimation results provide evidence that Paragominas farmers do not fully internalize the cost of fire use. The regime of complete internalization, stablished by the current law, does not seem to be enforced in practice.

It can be argued on the basis of the results obtained, that even if preventive measures such as firebreaks (Bowman et al. 2008), i.e. those unobservable from satellite imagery, are conducted by farmers, the protection they provide can be below the social desirable level, because the full cost of accidental fires is not faced by farmers. According to Shafran (2008) and Amacher et al. (2006), when only part of the cost is faced, farmers' investment in prevention tends to find an equilibrium below the socially desirable level. Unless clear internalization is enforced, farmers engaged in AFU will keep acting as if their neighbors are co-responsible for controlling fires they have not started, and a partial social protection against accidental fires will prevail.

The empirical exercise demonstrates that farm boundaries matter, and must be taken into account in 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.

5.References

Bowman, M.S., Amacher, G.S., Merry, F.D., 2008. Fire use and prevention by traditional households in the Brazilian Amazon. **Ecological Economics** 67, 117 – 130.

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.

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.

INPE, 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

INPE, 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

Morello, T.F., 2013. **Agricultural fire use in the Brazilian Amazon: some evidence for the state of Pará regarding the economics of accidental fires and fallow management.** Phd Thesis. University of São Paulo, School of Economics, Business and Accounting, Department of Economics. http://www.teses.usp.br/teses/disponiveis/12/12140/tde-13082013-201624/pt-br.php

Nepstad, D., Carvalho, G., Barros, A. C., Alencar, A., Capobianco, J. P., Bishop, J., Moutinho, P., Lefebvre, P., Silva, U. L., Prins, E., 2001. Road paving, fire regime feedbacks, and the future of Amazon forests. **Forest Ecology and Management** 154, 395-407.

Shafran, A. P., 2008. Risk externalities and the problem of wildfire risk. **Journal of Urban Economics** 64, 488–495.

Simmons, C. S., Walker, R. T., Wood, C. H., Arima, E., Cochrane, M., 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.

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., 2004. Contributions of fire use study to land use/cover change frameworks: understanding landscape change in agricultural frontiers. **Human Ecology** 32, 395-419.