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Analysis

Policy instruments to control Amazon fires: A simulation approach

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ABSTRACT

Agricultural fires are a double-edged sword that allow for cost-efficient land management in the tropics but also cause accidental fires and emissions of carbon and pollutants. To control fires in Amazon, it is currently unclear whether policy-makers should prioritize command-and-control or incentive-based instruments such as REDD+. Aiming to generate knowledge about the relative merits of the two policy approaches, this paper presents a spatially-explicit agent-based model that simulates the causal effects of four policy instruments on intended and unintended fires. All instruments proved effective in overturning the predominance of highly profitable but risky fire-use and decreasing accidental fires, but none were free from imperfections. The performance of command-and-control proved highly sensitive to the spatial and social reach of enforcement. Side-effects of incentive-based instruments included a disproportionate increase in controlled fires and a reduced acceptance of conservation subsidies, caused by the prohibition of reckless fires, and also indirect deforestation. The instruments that were most effective in reducing deforestation were not the most effective in reducing fires and vice-versa, which suggests that the two goals cannot be achieved with a single policy intervention.

1. Introduction

Fire is one of the major socio-environmental challenges facing the humid tropics, including the Amazon Basin. On the one hand, fire is an efficient tool to prepare, weed and fertilize land, and it provides profit and subsistence to a wide range of farmers from smallholders to large cattle ranchers. On the other, it is a source of escaped fires and atmospheric pollutants, a potential cause of soil degradation and a threat to rainforests, biodiversity and farmers' assets and health (Nepstad et al., 2001; Nepstad, 2007; Mendonça et al., 2004; Chen et al., 2011; Carmenta et al., 2013). Furthermore, the likelihood of disastrous wildfires this century is increased by predicted climate and vegetation changes linked to a higher frequency of extreme droughts, (Malhi et al., 2009; Chen et al., 2011; Coe et al., 2013; Davidson et al., 2012). For example, in 1998 fires in the Brazilian Amazonian state of Roraima affected over 5 million ha of forest (Cochrane, 2009, p. 17), while 2015 was the hottest year in the amazon over the last century (Jiménez-Muñoz et al., 2016).

Preventing an increase in the prevalence of fires in the Amazon and elsewhere requires policies that internalize externalities (Malhi et al., 2009; Sorrensen, 2009; Carmenta et al., 2013). In Brazil, one of the federal government's main responses to the fire problem is the controlled burn law, which replicates the ban-surveillance-sanction approach that proved highly successful for deforestation. Yet, to-date, there is no assessment of the impact of this policy on fires. Interventions are also occurring at local scales, including incentive-based initiatives of payment for avoided deforestation and avoided forest degradation (REDD+), as well as municipal actions supporting mechanized land preparation substituting for slash-and-burn (Simões and Schmitz, 2000; Börner et al., 2007, 2013; SEMA-AC, 2011).

The evaluation of impacts and limitations of command-and-control and incentive-based approaches to policy requires reliable empirical evidence. However, empirical work cannot provide definite answers without being guided by refutable hypotheses. This paper seeks to contribute with such hypotheses by developing an analytical device that represents the Amazon fire system both in the absence and presence of intervention. This is achievable with an agent-based, spatially-explicit simulation model. Policies, such as agricultural subsidies or payment ecosystem services (PES), aim to influence decisions with supra-individual consequences made by heterogeneous individuals. Policy interventions inevitably trigger a chain of connected processes whose net impact on the key state variables is not easy to intuit from pure reasoning without the support of an analytical tool. It is in this particular sense that a simulation model is useful (Zhao et al., 2012).

The use of spatially-explicit agent-based models for analysing policies, especially their implications for land use change, is growing in the literature (Kremmydas, 2012; Zhao et al., 2012). Examples include changes of the German and Italian agricultural subsidies (Happe et al., 2008; Lobianco, 2007) and incentives to adopt water-saving irrigation

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Table 1
Main uncertainties regarding Amazon fires.
Source: authors' research experience.

Question	Answer
Which is the share of remote-sensing fire detections related with: (1) Agricultural fires (1.a) Deforestation; (1.b) Fallow-based agriculture; (1.c) Pasture management and restoration; (2) Accidental fires.	Unknown, available remote-sensing data comprehends (i) point detections or "hotpixels" and (ii) "burned areas". With such information it is only possible to know the approximate location of fires and path followed, but not the finalities with which fires were started.
With which probability does an agricultural fire run out of control, turning into an accidental fire, and how does this depend on surrounding land use and fire control practices?	Unknown
Which are the economic returns of the following alternatives to fire: (1) Mechanized land preparation, conducted in small plots (3 ha at most); (2) Green land preparation (with fast-growing-N-fixing species and/or mulching); (3) Agroforestry (integrated crop and forestry).	A few field-based studies have produced cost and revenue data, but the information remains anecdotal.
Which is the rate of illegal fire users identified and sanctioned? Which is the rate of sanctioned farmers among the ones that have accidentally burned neighbors' land? Which is the rate of identified and sanctioned farmers among the ones that have caused wildfires?	Reports of these events are dissipated across the three levels of government. No comprehensive assessment is available. The number of undetected occurrences seems to be high for most Brazilian Amazon states due to lack of monitoring and the difficulty of identifying fire starters.

techniques (Berger, 2001). The focus on agents allows incorporation of interactions between landscape processes and human decisions as well as heterogeneity among decision-makers. In an explicit modelled space, land parcels influence each other being thus subjected to spatial spill-overs that may be engendered by policy.

Two are the main reasons for adopting agent-based modelling. First, its bottom-up approach enables multiple possibilities of individual and collective reactions to policy, including those that would prevent desired outcomes from being achieved or would favor undesired results. Second, it generates results with a level of heterogeneity/variability which reasonably resembles the data available for policy evaluation. However, regarding this second reason, a clarification is needed. Part of the richness of the results is very hard to reduce to refutable hypotheses that may guide policy evaluation. As producing such hypotheses is one of our main goals, we opted for a causal inference approach to simulation analysis (Marshall and Galea, 2014). This means focussing on comparing policy outcome variables in baseline and policy scenarios, rather than exposing the plethora of patterns the variables describe across time and space. The model presented in this paper is a tool to build knowledge on the potential results of policy options to reduce Amazon fires. Due to the scarcity of knowledge on this topic, we opt to focus the modelling effort on detailing a few key components of the Amazon fire system, mainly farmer behavior and policy instruments, and incorporate other aspects in a rather stylized way. This approach strives to maximize the usefulness of the exercise for empirical work, because scant existing evidence (Table 1) does not allow for testing of the intricate hypotheses that would be yielded by a more comprehensive model.

There is a further methodological reason for adopting a simple (or stylized) model. A clear trade-off exists between realism (the number and detail of real-world natural and social processes represented) and identification of causal effects (the confidence that observed variations in outcome variables are strictly due to variations in policy). Simulation models are different from models with analytic (pen-and-paper) solutions in that they do not necessarily yield identification. Non-linearity and stochasticity, coupled with endogenization of most variables, makes it hard to track the causes of the observed behavior of the main variables (Marshall and Galea, 2014). This difficulty grows with realism (El-Sayed et al., 2012; Cederman and Girardin, 2007; Townsley and Birks, 2008). We opt first of all for causal effect identification and pay the cost of reduced realism by greatly simplifying the Amazon fire system. The main benefits are the clarity and the empirical refutability of the hypotheses about the impacts of policy that can be derived from the results.

The policy background is synthesized in the next section and the model is presented in section three. The results are analyzed and interpreted in section four, followed by a brief conclusion.

2. Fire Policy in Brazil

2.1. Brief Overview

Policy interventions that affect Amazon fires include various initiatives that differ in terms of how directly they impact on fires, the level of government introducing the policy, the targeted social group and the type of policy instrument chosen. Here, we examine three key interventions. First, at the national level, the controlled burn law of 1998 regulates fire use by instituting licensing and monitoring (Brasil, 1998). It is a command-and-control instrument against agricultural fires that have a high probability of turning into uncontrolled fires and causing major damage (Brasil, 1998; Steil, 2009). However, in practice, permit granting is marginal (Toniolo, 2004, p. 193–194, Carmenta et al., 2013, Cammelli, 2014, p. 13, Costa, 2004, p. 184), enforcement is rare (IBAMA-PA, 2015) and recent fieldwork[1] indicated that few state and local governments execute these functions. The main barriers for the farmers are the transaction costs of obtaining the documents demanded by permit requisition, especially the proof of land ownership, travelling often long distances from farms to environmental offices in urban areas (Carmenta et al., 2013, Cammelli, 2014, p. 48).

Second, subsidies have been used to reduce fire and offer different routes for promoting the technological transition of smallholders to fire-free agriculture; mechanization and agroforestry. These include subsidies for mechanized land preparation offered by some municipal governments, generally together with extra financial support for agricultural inputs (Börner et al., 2007; Emater, 2015b; Simões and Schmitz, 2000). Alternatively, pilot projects are used to stimulate agroforestry systems, which combine trees, crops and animals in the same plot without resort to fire or inputs. The agroforestry pathway tends to be funded by NGOs and public institutions, and is advocated as "greener" and more sustainable than mechanization (Serra, 2005; Arco-Verde, 2008; MMA, 2009). However, progress on these fronts

[1] In April 2014 and March–April 2015 meetings and interviews with key stakeholders were conducted comprising national coordination of PREVFOGO and also Pará state headquarters, a short interview with Pará state institution on environmental surveillance (IBAMA-PA) and Pará state institutions on agricultural research (EMBRAPA CPATU) and rural extension (EMATER).