Fire risk and smallholders in the Brazilian Amazon: why have institutional arrangements failed so far?

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Abstract. In the Brazilian Amazon, uncontrolled fire is one of the main drivers of forest degradation leading to important loss of biodiversity and ecosystem services (ES). Smallholders are often considered as the main actors responsible for these damages, as they commonly depend on fire for agricultural management activities. Since the 1990's, different policies and actions have been implemented to control fire use, but with limited success and fire continues to be an important problem in the region. With the perspective of engaging a participatory policy with stakeholders and realistically bring about a transition out of fire in the Amazon, we take stock of current knowledge on fire from different science realms and understand how this knowledge has influenced policies and institutional arrangements launched in the region up to date. Building on a theory of compliance, we overview the policies developed to reduce fire in the Brazilian Amazon and identify through a review in the recent literature the reasons associated to the generalized non-compliance observed until now. Our analyses show that policies launched so far have been focusing solely on the negative impacts of fire and as such, radically ban the use of fire in a way that is at odds from the practices and motivations of local actors. This flaw explains the failure of institutional arrangements in stimulating compliance related to fire risk in the region. We sum up the different challenges that need to be addressed to build more effective institutional arrangements, which would be more adapted to the actors' motivations and able to encourage environmental services conservation.

1. Introduction

While deforestation in the Amazon has decreased by more than 80% in 8 years, many studies have showed an alarming increase in forest degradation mainly caused by accidental fires that lead to forest degradation and threaten important ecosystem services (Aragão et al., 2010; Soares-Filho, 2012).

In tropical regions, fire is a challenging issue, as it is widely used for agricultural practices, causing a multiplicity of annual ignition sources (Sorrensen, 2009). Although fire is used both by large landowners and small-

scale farmers, there is a generalized scientific and policy rhetoric against smallholders, who are blamed for continuing to make swidden fire (Costa, 2006). Forest wildfires and swidden fires are distinct realities, but many studies tend to make an overlap, impeding proper understanding of the determinants of fire (Carmenta, 2013). Intensification of accidental fires is generally attributed to a combination of increased forest inflammability, of agricultural practices, but also of changing social settings, with increased anthropic pressure (Uhl & Buschbacher, 1985; Sorrensen, 2009). Although each of these determinants is covered by literature, linkages between spheres of knowledge are rare. Difficulty to apprehend the complexity of the fire phenomenon thus often leads to oversimplification, miscomprehension, and a dominant negative discourse of fire and its effects (Carmenta, 2011). This has different pervasive effects, as fire becomes apprehended as uncontrollable and badly managed, often leading to prohibition policies, which have limited impact as they fail to address the drivers of the use of fire (Sorrenson, 2009) and close space for discussion on this issue (Mistry, 1998). In other cases, fire risk is simply ignored or evacuated from the debate, which leads to propose ingenuous policies, such as is currently the case in the debate regarding REDD+ mechanism (Barlow et al., 2012).

To propose more adapted policies, Mistry & Bizerril (2011) consider it is urgent to build a better comprehension of the motivations that lead farmers to use fire. There is evidence that motivations are very different between types of farmers. In recent years, the strong command-and-control policies put forward by the Brazilian federal government to limit deforestation have been quite effective with large landowners, as these policies cut credit and markets if environmental compliance was not proved (Assunção et al. 2012, 2013). However, their effect on small-scale farmers was limited, as these are excluded from such market dynamics and have motivations that are mainly affected by social and livelihood concerns (Coudel et al., 2012). Some authors consider that incentives would be a relevant option (Börner et al., 2010), but they might be just as inadequate if focus continues to be on the policy conception without understanding farmers' motivations (Kosoy et al., 2008).

With the perspective of engaging a participatory policy with stakeholders in the Amazon to realistically bring about a transition out of fire, we take stock of current knowledge on fire use and understand how this knowledge has influenced policies and institutional arrangements suggested up to date. We will show that by bringing evidence mainly on the negatives effect of fire, science has contributed to radicalize policies against fire, bringing them at odds from the practices and motivations of local actors and thus undermining compliance First, we present the premises of a theory of compliance which understands compliance as the result of a balance between institutional arrangements and individual and collective motivations. In the second part,

we present the knowledge on fire build by ecological, agronomical and social sciences. In a third part, we overview the policies developed specifically to reduce fire in Brazil since the 1990's and identify the institutional conditions they led to and what are the reasons given by recent literature for the generalized non-compliance. Finally, we sum up the different challenges that need to be addressed to build institutional arrangements which would be more adapted to the actors' motivations and thus better encourage preservation of environmental services.

2. Theoretical framework for compliance

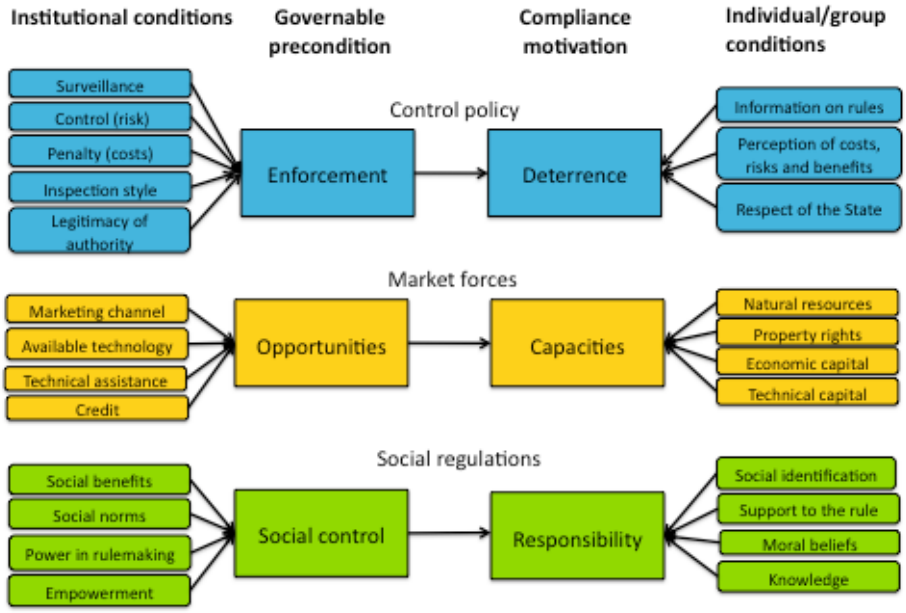
Considering the observation of generalized non-compliance to fire policy (Sorrenson, 2009; Mistry & Bizerril, 2011; Carmenta, 2013), it seems important to comprehend what determines the (non-)efficiency of a policy. A common view will bring elements on the failings of the institutional context, because of lack of funding or of capacities (Sorrensen, 2009). Although we find the contribution of such studies worthy, we wish to go a step further and show that, more fundamentally, the rationale behind these policies is inadequate. We thus aim at bringing light on the knowledge underpinning these policies.

Different theories have been developed to understand the link between science and policy, such as the triple helix in which the state, firms and civil society interact during the policy conception phase, or the actor-network theory, which decomposes the networks of science in the making (Callon et al. 2001, Akrich et al. 2006). However, these theories focus mainly on the process through which scientific knowledge is integrated and translated into policies, but they do not address the political consequences (Lamy, 2007). This is precisely what we wish to explore, by analyzing how the knowledge integrated in a policy will lead it to be more or less consistent with the motivations of actors to change their practices or not.

Policies and regulations are varyingly interpreted, modified and ignored by actors at different levels of social organization, leading to differences in "rules in use" (Farber, 1999; Ostrom, 1990). The behavior of people to conform to the rules that are intended to regulate their actions is defined as compliance (Hauck, 2007). The efficiency of a policy depends critically on achieving a high level of compliance. In the theory suggested by Gezelius and Hauck (2011), compliance is the result of a balance between institutional preconditions and individual or group motivations. Motivations to comply vary according to the type of institutional conditions, divided into authority, economic incentives, social norms, or responsibility building (Gezelius and Hauck, 2011; May, 2004; Winter and May, 2001).

Inspired by the Gezelius & Hauck framework, we developed our own framework (**Fig. 1**). We will present its sub-elements in the following parts of the paper, as we use them for the analysis. Based on the review of different papers addressing fire and policy, we analyze the institutional arrangements and individual or group motivations in the context of the conceptual framework presented.

Fig. 1. **Conceptual framework relating compliance to governable preconditions**



3. Knowledge and perceptions of fire from different realms of science

Although slash-and-burn practices have been documented since European colonization of the tropics, fire gained wider interest within the scientific community in the early 1990s, as ecological findings revealed the broad destructive effects accidental fires had on tropical forest and ecosystem services associated (Sorrenson 2009, Mistry 1998). Fire increasingly became recognized as a ubiquitous problem in Amazonian landscapes, as it led to

important ecological, economic and social losses (Nepstad et al. 1999, Mendonca et al. 2004).

3.1. The ecological point of view: fire as a threat to crucial ecosystem services

Ecological studies have mainly focused on how forest fires impact ecological systems considering their many different elements such as species diversity, biomass stocks or soil nutrients cycling (eg. Barlow & Peres 2008, d`Oliveira et al. 2011). Forest fires in a larger scale can affect many ecosystem services (Cochrane 2003), including provisioning, regulating or cultural services.

Regarding provisioning ecosystem services, uncontrolled fires destroy natural and agro-ecosystems that may contain important cultivated food, fiber or timber and non-timber forest products which overall contribute to food security and well-being. Many studies in the literature report drastic and long term reduction of forest biomass after burning in a mature forest, where more than half of the bigger trees were killed (Barlow and Peres 2006). Forest fires also affect fauna and flora species composition as demonstrated by numerous researches in tropical areas where fire use by agriculture is predominant. Plant species composition usually evolves toward species more adapted to open areas with lower wood densities (pioneer species) in detriment of shadow tolerant species with hard wood that are typical in mature forests (climax species). Changes in overall resource availability and environmental conditions lead to significant alteration in animal species composition (eg. Lees & Peres 2006, Barlow & Peres 2006). In general, modifications in biological diversity mediated by fire result in local (and possibly regional) extinction of more rare species that usually are the most sensitive to changing conditions.

Overall, these changes result in diminished capacity to provide forest resources such as timber for local communities that rely on such resource for their livelihoods or non-timber products extracted from trees such as resins, exudates, bark, foliage, fruits, seeds and fuel wood are also affected (Ferreira et al. 2012). Affordable sources of protein for local human communities through hunting can vanish after repeated forest fires. Ecosystem changes and biodiversity declines resulting from forest fires invariably affect important cultural ecosystem services.

Effects of fire on regulating ecosystem services can be less obvious than provisioning services, at least in a short term, but may have strong consequences on the global scale. One of the most important is the massive contribution of fires to overall greenhouse gas emissions (GHG), which

ultimately affects planetary climate regulation. CO_2 emissions from shifting cultivation in the Americas, for example, was estimated as an average of 295 million tons per year (Silva et al. 2011). Reduced humidity and lower local precipitation is another important potential consequence of forest fires in regulating ecosystem services. This impact occurs mainly because of positive feedbacks loops with decreasing water vapor flux from the degraded forest to the atmosphere (Nepstad et al. 2001).

However, confusion between forest fires and swidden fires seems to mislead towards dramatic conclusions regarding use of swidden fire (Carmenta, 2013). Although swidden fires are often responsible of such accidents, very few studies qualify the debate separating impacts of well-controlled swidden fires and the impacts of large-scale fires (Sorrenson, 2009). In fact, the ecological impacts of well-controlled swidden fires are expected to be lower than those of intensive farming. This argument has been used to support the maintenance of shifting cultivation agriculture that is so importantly embedded in the tradition and livelihood of smallholders worldwide (Padoch & Pinedo-Vasquez 2010). Slash-and-burn usually produces a patchy habitat of agricultural plots, fallow and old-growth forests, which may favor a biodiversity mosaic (Padoch & Pinedo-Vasquez 2010). It thus seems important to better qualify the debate on extensive versus intensive agriculture (see Phalan et al. 2011). Moreover, the overall carbon loss of a slash-and-burn system may be at least partially compensated by the recovery of biomass if land-use intensity is not excessively high (Omeja et al. 2012, Chazdon 1998). The rate of recovery however depends on many factors such as land-use intensity and natural factors as soils and climate conditions (Gehring et al. 2005).

Thus, most ecological studies on fire bring knowledge on its devastating effects on ecosystems, often relating them to agricultural use of fire. Links with swidden fires exist, but since they are rarely investigated, conclusions on the impact of swidden fires may be distorted.

3.2. The agronomical point of view: fire as a cost-effective management practice

Although agricultural studies acknowledge that fire is a cost-effective management practice, research efforts have mainly been invested in developing alternatives to fire (Pollini 2009).

In the Brazilian Amazon, fire is widely spread practice given the lack of equipment, the limited access to inputs (especially for small farmers) and the large forest areas. Fire is used as a substitute of mechanization, expensive pesticides, or simply of hard work (Siegert et al. 2001). Fire is commonly

related to deforestation, although it is used both for clearing forest or for cleaning already opened areas (such as pastures). Fire is traditionally used by swidden agriculture, in which farmers clear small areas (on average 1 to 2 ha) to plant annual cultures (mainly cassava, but also corn, rice, and a diversity of other plants). With the colonization of the Amazon region for cattle raising, fire has become used to clear forest to plant pasture. Small farmers have also started combining areas with shifting cultivation and permanent pastures, often compromising the fallow cycle.

Agronomy studies show that fire offers several important advantages, such as the vegetation removal and its transformation into ashes, bringing a temporary fertilization. They act as a source of nutrients, especially phosphorus, also increasing the content of exchangeable cations and the pH of acidic soils (Martins et al. 1991), which are common in the Amazon region (Sánchez 1981). Another advantage is that fire also helps control weeds and pests. It enables a clear start in the case of slash-and-burn, and in the case of pastures, it helps controlling undesirable species (both plants and animals) (Mistry 1998).

However, fire also causes loss in the organic matter of the soil, which is the main reservoir of nutrients for the ecosystem (Sánchez 1981), negatively influencing carbon storage (Martins et al. 1991). Therefore, the positive effects of fire are valid only for a short period of time (one to two years). Moreover, a repeated use of fire will highly degrade the soil and diminish agricultural production (Lawrence 2005, Styger et al. 2007). Farmers generally rotate areas where they use fire (Mistry 1998), but with increasing anthropic pressure, rotation and fallow period become limited.

Although fire is a primordial agricultural practice that has been used in many regions of the world (Mazoyer & Roudart 2002), it is often stigmatized as a lagging practice, used by smallholders who need "modernizing" (Costa 2006; Carmenta 2013). Building on the argument of limited fallow period and short term benefits of fire, agronomy studies have aimed at identifying alternative methods, more than addressing other ways of managing fire (Pollini 2009). Slash-and-mulch (where fallow is finely slashed and left as ground cover to form mulch), direct planting combined to green fertilizers (using the same open area), mechanization with application of artificial fertilizers, are some of the options (Kato et al. 1999; Denich et al. 2004, 2005). Studies reveal that on the plot, these systems have important benefits. An experimental study in Eastern Amazon demonstrated that GHG emissions in a traditional slash-and-burn plot were at least five times higher than a fire free rotation system with slash-and-mulch (Davidson et al. 2008).

However, whilst the dynamics of nutrient flows and other biophysical aspects advance, much less research has focused on exploring drivers of

smallholder uptake of alternative technologies to fire. In fact, these agronomical considerations seem to be little taken into account by farmers to choose between fire use or other production alternatives. Labor saving and financial advantages of alternatives have been put forward by research (Denich et al. 2005), but have not seemed to convince the farmers (Pollini, 2009; Villemaine et al. 2012).

Although alternatives to fire may present different technical advantages, the perceptions of farmers on fire use and its advantages and limits is more determinant (Mistry, 1998). Since agronomy studies have mainly aimed at finding alternatives to fire to recreate optimal soil conditions, largely ignoring (or even disdaining) fire management options and its advantages, they have overlooked an important aspect of the debate (Pollini, 2009).

3.3. The social sciences point of view: fire as a risk to be managed

On the contrary of other disciplines, social sciences investigate how farmers consider fire and manage it (Mistry, 1998), without developing a rhetoric against fire. However, a certain rational-centric vision leads to consider risk as a central element of decision making, whereas there is little evidence that perception of fire risk is that important.

Capacity to engage in fire prevention is usually considered to depend on available household time or labor wages (Bowman et al. 2008). Mistry (1998) shows however that the perception farmers have of fire is determinant in influencing their fire management practices and adoption of alternatives, depending on what they consider the “good” and “bad” aspects of fire. These perceptions are determined by age, education, experience, and intergenerational relations (Mistry & Bizerril 2011).

It is commonly considered that farmers will weigh the risk associated with fire to the possible damages it may cause, such as destruction of existing plantations of standing forest reserves (Bowman et al. 2008). However, risk evaluation may not always be rationale (Brondizio & Moran, 2008). When individuals misperceive risks, their behavior may differ from what is expected (Winter et al. 2010). For example, increase in forest inflammability does not seem to be perceived, leading to continue traditional practices (Brondizio & Moran 2008). Indeed, traditional populations would rely on the nearby moist forests to contain the blaze (Simmons 2004, Wetzler and Omi 1991), and still today, small-scale farmers seem to be more preoccupied in achieving a good burn to eliminate all detritus than in limiting the risk of fire escaping (Carmenta 2013).

Moreover, the perceived controllability of a risk will influence whether individuals believe it is worthwhile to take protective action or not (Slovic,

1987). Carmenta (2013) shows that the farmers she studied don't believe firebreaks can do much to against fire when it gets out of control and thus don't include this in their management practices. Perceived responsibility for risk also plays a significant role in determining which risks are ultimately reduced, and by whom. Responsibility for controlling wildfire risk is generally viewed as having both public and private components, because actors all contribute to this risk and share, to varying degrees, in the consequences of destructive outcomes (Winter et al., 2010). Studies suggest that this can create a free-rider problem, if farmers are unwilling to invest in fire control let fire escape neighboring properties and cause damage (Simmons et al. 2005).

These studies refer to the importance of community rules in limiting the free-rider problem, mainly for resource management (Agrawal and Ostrom, 2001). However, hardly any study investigates this collective aspect of fire control. Simmons et al. (2004) test relations between political organizations along roads (*ramais*) and fire damage and find no conclusive result. Some studies show differences between traditional communities and more recent settlements (Bowman, 2008; Brondizio & Moran, 2008; Toniolo, 2004), which can be explained by a difference in practices but also by more social relations within the traditional communities. According to Brondizio and Moran (2008), the rate of population turnover in the Amazon undermines the availability of rural populations to learn, share, and develop forms of individual adaptation and collective action to cope with climate change or fire. Field studies show that in practice, relations between neighbors regarding fire is rare, if not inexistent, impeding higher collective control (Mistry 1998, Carmenta, 2013).

Fire risk may in fact be of little concern in comparison to other risks. Brondizio & Moran (2008) suggest that farmers may evaluate the risk of changing their livelihood strategies to the risk of avoiding change. Studies have showed that often, people would rather live with risk than uncertainty, bringing them to favor well-known but risky situations (Brondizio & Moran, 2008).

Although social studies investigate fire management without any negative bias against, ground studies are still rare (Carmenta 2013) and comprehension of fire perception and drivers of fire management is mainly exploratory.

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Extensive ecological studies have investigated into the impact of fire and its consequences on ecological systems. Building on the same logic, agronomy studies have mainly shown the potential damages fire can cause, without looking into its advantages, and thus focus on developing alternatives to fire. In both cases, there is a certain negative bias regarding fire, impeding

to a more thorough understanding of the risks but also the advantages of fire use in agriculture. Although social case studies have looked into the perception of farmers on fire management, systematized knowledge is still scarce, and the few case studies show that applying risk theory or collective action theory may be misleading.

4. Policies and institutional arrangements for fire prevention

Although policies against wildfires in the Brazilian Amazon have been implemented since the early 1990s, their success is limited, wildfires still widely prevailing. Several studies show that these policies were influenced by the scientific community (Costa, 2006; Sorrensen, 2009; Pollini, 2009, but it seems that in most cases they were based only on mainstream scientific evidence, which led them to adopt a strong negative bias against fire, distant from the reality of farmers.

Improved fire management and prevention will only be possible when we understand better the motivations which lead people to widely use fire and build policies accordingly (Mistry, 1998). As we present the different policies developed in the Brazilian Amazon to prevent fire and the rationale behind them, we will assess their success and limits by bringing light on farmers' motivations and capacities to comply.

4.1. Governmental monitoring and prohibition

The warnings of ecological sciences on damages of fire on ecosystem services, combined to extreme fire events (1987, 1998), had strong repercussion within international institutions (in particular the World Bank) during the 1990s, bringing them to condition loans and support to Brazil to the implementation of command-and-control policies against fire (Sorrensen, 2009).

In general, command-and-control policies act through monitoring and control, enforcement varying with the size of penalties and changes to the style of inspections (May, 2004). But the efficiency of command-and-control policies depends upon the risks perceived by actors of being caught and punished, the benefits of not complying with the law, as well as on levels of respect for law and the State (Gezelius and Hauck, 2011) (**Fig. 1**).

4.1.1. Enforcement conditions

Initial focus of fire policies was on conservation units, with the PrevFogo (Sistema National para a Prevenção e Combate de Incêndios Florestais),

launched in 1989, who trained 5000 volunteers to combat fire hazard in these units. However, the 1998 fire in the Amazonian state of Roraima (which destroyed 10.000 km2 of primary forest) made apparent that this policy was not enough to face large-scale threats outside conservation units (Sorrensen, 2009).

This led to strengthen enforcement of prohibitive policies regarding use of fire in private properties. In 1998, a law on environmental crimes gave Brazil's environment agency IBAMA the mission to investigate and punish environmental crimes. The initiative was to enforce the Forest Act, which made burning without precautions illegal in private properties (since 1934). Burning licenses were required for any use of fire on private properties. However, capacities to deliver the licenses and to control private properties were low. In some states or municipalities, local laws chose to totally prohibit fire use, as in the state of Acre, evacuating the problem of delivering the licenses, but with no more capacity to control this fire ban.

In parallel to this increased enforcement, an exceptional 10-year program was initiated in 1998, to contribute to prevent and monitor fire in private properties in the « arc of deforestation »: the ProArco (Monitoramento de Queimadas e Prevenção e Controle de Incêndios Florestais no Arco do Desflorestamento na Amazônia), through an emergency loan by the World Bank and support of PNUD. It combined educative prevention programs and the development of monitoring capacities, through satellite imagery. The development of remote sensing technology, which enabled to monitor fire through hot spots and fire scars, misled into considering that fire would be under control (Sorrensen, 2009). However, given the size of the Amazon and land occupation uncertainty, identifying hot spots is far from identifying culprits or being able to find them. Moreover, some researchers warn that remote sensing tools introduce an important asymmetry and bias regarding fire monitoring. For example, using the information reported in “hot spot” pixels, many aspects of the problem may still remain unknown such as the intensity of fire, the type of vegetation burnt, how fires were started, whether they were agricultural or accidental (Sorrensen, 2009).

4.1.2. Level of deterrence and perception of authorities

Besides the problem of enforcement and monitoring, different authors show that fire prohibition policies also greatly lacked legitimacy with local population. Mistry (1998) carried out a detailed study of farmers’ perceptions in the Brazilian savanna regarding the law and why they were compliant or not. He shows that most farmers knew that fire laws existed, but 65% of them were ignorant of the license permission needed to use fire and none knew of the procedure for obtaining it. In fact, obtaining this license can be fastidious, as it requires appearing in person in the environmental office (generally in the

capital) between 30 and 15 days before the date of fire and declaring an exact date. Carmenta (2013) shows through an ethnographic study that farmers in a region of the Amazon were generally incapable of saying exactly when they will burn, as it depends on]many] climatic conditions, as well as household availability.

Mistry & Bizerril (2011) also shows that farmers are often wary of government officials from IBAMA, mistrusting them as they are supposed to monitor and enforce prohibition. Farmers perceive that institutions condemn them for their use of fire rather than help them to find alternatives. These authors also point out how delicate the situation is for local staff of IBAMA: they fail to enforce the federal requirements demanded by the central agencies based in the capital, but at the same time they have no autonomy to make local agreements to promote controlled burns (Mistry & Bizerril, 2011).

Fire prohibition policies aimed at limiting destruction of forests by limiting ignition sources, with a narrow interpretation of ecological studies. They proved to be insufficient because of limited monitoring and enforcement capacity, but also because they greatly lacked legitimacy with local actors, as they were incapable of taking into account their reality. This confirms analyses of command-and-control policies in other domains, where the capacity for state enforcement is lacking and where policy is conducted out of context of the practical realities of regions where laws are intended to be applied (Gezelius & Hauck, 2011).

4.2. Encouraging alternatives to slash-and-burn

The knowledge brought by the agronomy community mainly contributed to define alternative technical models. Policies have focused on encouraging demonstration units, considering adoption of fire-free practices would naturally expand, but have largely overlooked how to favor the conditions which would enable farmers to adapt their agricultural practices.

Compliance studies show that adoption of new practices depends both on technological and market opportunities, and on the adaptation capacity of the farmers (Winter & May, 2001) (**Fig. 1**).

. *4.2.1. Technical opportunities*

Although intensification of land use has been viewed as an important solution against fire, policies in this perspective have long been limited to encouraging research to develop alternatives. Several programs were carried out, from the mid-1990s to current days, through international partnerships: ASB (*Alternative to Slash and Burn*), coordinated by ICRAF ; Tipitamba led by the Brazilian agronomical research institute EMBRAPA (Belém) initially

in cooperation with German institutions (Denich et al.., 2004, 2005); FLOAGRI, led by Embrapa and Cirad (Sist *et al*., 2010). There was a certain belief that such innovation would naturally expand (Pollini, 2009). Even though these programs were carried out through field experiments within farmers' properties (Oliveira *et al*., 2009), adoption in the areas remained very limited, even after more than 10 years of research presence (Pollini, 2009 ; Villemaine, 2012). Economic viability of these systems may be an issue (Börner *et al*., 2007; Drigo *et al*., 2013), but Villemaine et al. (2012) also show that local institutions (in particular technical assistance and banks) remained external (and dubious) to these programs, impeding the development of sociotechnical innovation networks which would be necessary for the up-scaling of such alternatives.

Sorrensen (2009) considers that the main limitation to fire prevention is the lack of a supportive institutional context, namely for technical assistance, credit and land regularization. For example, between 1985 and 1999, over 57% of the families settled by INCRA (the Land Reform Institute) were in Amazon region, but they received 3 to 11% of total credit funds (Sorrensen, 2009). In fact, most small-scale farmers don't have any title, impeding access to credit, and often leading to high turnover in land settlements. Some studies have proved that when farmers are permanently settled, they reduce the amount of fire use in agricultural practice (Almeida & Uhl, 1995), revealing the importance of land regularization.

But as Villemaine et al. (2012) point out, such institutional limitations are not inescapable. Innovation does not only depend on its technical-economical potential and on the institutional context, but also on how farmers and other stakeholders will take up this issue, depending on their interests. Based on this political view, Villemaine et al. (2012) argue that currently, it is not only the institutional capacity which is lacking but also interest of the institutions in alternatives. Almost all credit is directed towards cattle breeding which benefits from strong economic drivers, as large-scale breeders need small-scale farmers. Moreover, municipalities and banks generally put forward tractors as the solution against fire, seen as a modern technical model, enabling good credit business, and stimulating the development of the machinery sector (Villemaine et al. 2012).

Since 2009, the federal government has tried to develop a more supportive context by launching the "Arco Verde" program, mainly as a way to show it could also be supportive after the strong command-and-control operation "Arco de Fogo" in 2008. This program aimed at accelerating land regularisation (with the Terra Legal program) (Dezorzi et al., 2011) and encouraging pilot farms with support of Embrapa in each of the 43 municipalities targeted. The Terra Legal program has been much delayed and pilot units are just starting, making it difficult to estimate its possible success.

4.2.2. Adaptation capacities

Field studies to understand why alternatives to slash-and-burn are not adopted show that farmers see them as a costly investment, requiring more work and bringing little return the first years, and allege difficulties in access to information, inputs, equipments and credit (Mistry, 1998; Börner et al. 2007; Drigo et al. 2013; Villemaine et al. 2012). Other authors show that household strategies in relation to fire are also influenced by limited access to markets and labour (Bowman et al. 2008)

One of the main stakes is to understand farmers' strategies within the broader farming system (Deffontaines and Petit, 1985; Landais and Balent, 1993). Although agronomy studies see the advantages of such alternatives through a productivity lens, putting forward the high yields and little degradation, farmers take into account a much broader view to choose options. Pollini (2009) argues that cropping systems are generally part of a combination of activities and that farmers do not specialize in the most profitable one according to simple criterion. They prefer combining a larger range of crops, to avoid dependence and minimize risk. Even farmers who develop alternatives such as agroforestry will continue to use fire in cropping systems to guarantee food security (Pollini, 2009). Thus, market access may not have as much influence as alleged, as subsistence involves very different motivations (Gezelius, 2004).

Brondizio and Moran (2008) point out that adaptation is not only a matter of individual choice, but depends on the wider community. They refer to social differentiation, but also to the environmental context. Indeed, in a fire-prone community, investing in fire-free alternatives (in particular in perennials) may be discouraged by the risk of destruction by accidental fires (Nepstad et al 1999, 2001; Pokorny et al., 2012).

Policies for alternatives to slash-and-burn are still rare, and they tend to focus only on productivity issues, ignoring that farmers decide their practices within a larger farming system. Several authors consider that small-scale farmers in fact don't yet have the option of turning to alternatives to fire because of the lacking institutional context (Sorrensen 2009; Mistry & Bizerril 2011).

4.3. Promoting rules to manage fire risk

The knowledge built by social sciences follows a different dynamic in relation to policies. It is part of an iterative process, between actions carried out by local institutions and movements, analysis by scientists and up-scaling through policies.

Social regulations, including trust, recognition within a group, and moral beliefs have gained increased importance in analyses of compliance

motivations (Ostrom, 2005). Policies to promote such arrangements are generally based on efforts to decentralize power and control (Agrawal and Ostrom, 2001; Ostrom, 1998), in order to give greater legitimacy to rules, as they become better adapted to local contexts. Nevertheless, local enforcement capacity remains an important precondition (Gibson et al., 2005). It also depends on the sense of responsibility and awareness developed by local actors (Tomer & Sadler, 2007) (**Fig. 1**).

4.3.1. Social control and empowerment

Seeing the limits of the command-and-control and of the innovation paradigms, different initiatives progressively emerged in the late 1990's to promote "best-practice" rules to manage fire within smallholder communities. The forerunner initiative was led by IPAM (Instituto de Pesquisa Ambiental da Amazônia), an NGO[1] who worked on fire impacts on ecological systems. They developed the program "Bom Manejo de Fogo" which involved coordination of local communities, collecting information on practices linked to fire to establishing an agreement on fire with the communities[2](Carvalho et al., 2007). Carvalho et al. (2007), who implemented this program in the National Forest Reserve of Tapajos (located in Santarem, Pará), assess that agreements were developed with almost half the families living in the Reserve, and that during the years in which the program was carried out in the reserve (from 2001 to 2004), accidental fire was reduced by 75% (previously, accidents were reported for 61% of swidden fires, and decreased to 13%). In 2003, the Ministry of Environment invited IPAM to formulate the new national policy within Proarco, to promote environmental education of community leaders (Carvalho et al., 2007).

Other similar actions were initiated in the early 2000s: NGO-led initiatives, such as Fogo Emergência Crônica (Friends of the Earth); federal networks such as Proteger (Grupo de Trabalho Amazônico, with 500 institutions); international partnerships, such Amazônia sem Fogo, between Brazil and Italy, now extending to Bolivia (Costa, 2006; Carmenta, 2013). In an extensive and thorough analysis of these initiatives, Costa (2006) reports that all the information campaigns carried out by different programs followed similar features, in the forms used by communication and in the suggested rules. Costa (2006) estimates that the communication models (meetings, leaflets) they used often limited the possibilities of interaction with local

[1] Founded by reknown ecology scientists such as Daniel Nepstad, which shows the links of such actions with research.

[2] The "best practices" promoted by the agreement were amongst others: choose well the place to clear ; give notice to the neighbours; ask for burning licence; bring down dry trees; wait for the first rain; make fire breaks; burn during cool hours; take water to the burning spot; monitor burning.

farmers. They presumed that fire practices were unknown or "inappropriate", and that by sharing information on "best practices", they could raise awareness on fire management.

4.3.2. Awareness and responsibility

Costa (2006) shows that reduction in hotspots following these experiences was only temporary and that practices encountered a few years later differed from the best practices recommended. Carmenta (2013) observes a similar mismatch between what people reported doing and what they actually did (81% report making firebreaks, but only 7% do), revealing that they are aware of best practices, but can't implement them (eg. bringing water to the burning site) or consider them as inadequate (eg. firebreaks are considered futile).

These findings reveal the different conceptions of the fire risk and of what would motivate farmers to take prevention measures. Sorrensen (2009) estimates that policy and programs tend to see fire as an emergency, when at the local level, fire is something much more familiar, to which smallholders have nuanced attitudes, seeing no urgency in changing. Moreover, several authors point to the fact that many traditional farmers (such as caboclos) have a different conception of losses and damage. Our own experience in the field has showed that loosing annual crops is not considered through individual economic valuation, as farmers can count with the solidarity of the community.

Escaped fire is never reported to be sanctioned (although strong sanctions can exist for other acts, such as theft) (Carmenta 2013, Mistry 1998), probably because in the local viewpoint it is considered involuntary and a fatality which could happen to anyone. When asked about recuperation of damages, traditional farmers did not understand, considering this as a strange conception (Carmenta 2013). Community responsibility for fire accidents is rarely admitted, farmers (or dwellers) often accusing people external to the community for fire start (Winter & Fried 2010). In fact, the risky nature of fire makes it difficult to investigate the effort put into the control or the intentionality. Kull (2002), in Madagascar, investigates the issue of "criminal" or "protest" fires, in which farmers intentionally let fire escape control, to then take advantage of the situation. However, such studies have not been carried out in the Brazilian context.

Costa (2006) alleges that the main interest of farmers in participating in definition of "best practice" rules may in fact not be to limit fire damage. Studying the power relations established during the information campaigns, she concludes that for farmer institutions, these discussions were often the first time they were invited to take part in determining NGO agendas and in policy making. For them, this was an opportunity to gain access to a political field in which they could negotiate what really interested them, which was developing economically viable production systems.

Although education programs did not condemn fire use, they relied upon very few studies and knowledge about fire management practices. This has led them to a certain ingenuousness, regarding the reasons why farmers used "inappropriate" management practices, their perception of fire risk and the fact that community control and sanctions did not make sense for fire.

5. Discussion

Based on the analysis of current studies on fire, we take stock of previous policies and institutional arrangements and point to their limitations. As presented earlier, we chose not to focus on the failings of the institutional arrangements in terms of capacity and funding, but on the rationale behind the policies and programs. Our objective was to identify the way policies think they will solve the fire problem and see if the conditions they suggest are in line with what could motivate actors to change. This has led us to question the types of knowledge used by policy making and their relevance given farmers' motivations.

5.1. How has knowledge about fire influenced policy?

The first point our analysis shows is that the knowledge used to base policies is characterized by a bias against fire which makes it distant from local realities. Since most studies were initiated following a context in which fire had destructed large forest areas, they tended to radically ban the use of fire, disregarding local practices. Ecological studies characterized the large environmental impacts, but brought little information regarding the causes and origin of such large scale fires. Thus command-and-control policies focused on reducing ignition sources from small-scale farming, in a context where most livelihoods still depended on fire (Sorrensen 2009). Agronomy studies mainly suggested alternatives to fire, instead of contributing to a better understanding of how to improve fire management (Pollini 2009). In a context where supportive institutional conditions to alternatives are clearly lacking, bringing radical change rather than incremental change is questionable. Some social studies tried to better characterize perception of fire and management practices (Mistry 1998; Carmenta 2013). However, in the absence of more systematic studies on fire practices, education programs tend to consider farmers use "inappropriate" practices because of a lack of information, and that communication campaigns would be sufficient to bring change in practices (Costa, 2006).

Limitation of current scientific knowledge on fire is a growing preoccupation (Carmenta et al. 2011, Mistry & Bizerril 2011). First of all, the

bias against fire must be overcome. Studies ought to question "established truths" against fire which only lead to ban fire (Pollini 2009). For this, scientists must accept that farmers voice the research agenda, as has occurred in European countries, where research has been progressively brought to work together with farmers on their fire practices (Ribet 2005, Bernard-Laurent & Weber 2007). One of the stakes is to detach swidden fires from the anti-fire narrative and large forest conflagrations (Carmenta 2013). There is also a need to investigate with scientific tools the rationale behind current fire practices, instead of considering they are irrational beliefs (Mistry & Bizerril 2011). Secondly, although some studies cross ecological and social aspects, there is a general lack of understanding of feedback between levels and determinants. Better understanding fire escape and fire spread from a mixed ecological and social approach would help determining more precisely the risk involved in agricultural use of fire and could lead to fruitful discussions with local actors. Thirdly, ground-based studies to identify determinants of fire use and management solutions are insufficient. Pollini (2009) warns against the trap of proposing the solution before understanding the context and considers that it is fundamental to analyze pathways taken by local actors to address their changing environment. In this perspective, authors call for more participatory approaches to explore possible solutions to the fire issue (Carmenta et al. 2011).

5.2. Are policies consistent with motivations to use fire?

The second point we bring through is that motivations to manage fire or change practices are not as simple as those expected by policies. Command-and-control policies assume that farmers will fear being caught burning without a license, but farmers are hardly aware of such conditions and as they depend on fire for their livelihood, they consider such measures as totally illegitimate (Mistry 1998). Innovation policies seem to assume that farmers will also wish to increase crop productivity and limit soil degradation, but farmers do not seem to be aware that fire causes such agronomical problems (Mistry 1998) and develop other strategies to compensate potential losses (Pollini 2009). Education policies consider that farmers will be enthusiast to discover risk limiting practices, but in fact, farmers seem to have a different conception of risk, and the risk of changing may be higher than continuing practices they know work (Brondizio et Moran 2008; Carmenta 2013). Other studies also suggest that social control may have an important role in controlling fire risk, but turnover in communities is high, impeding such dynamics (Brondizio et Moran 2008).

Gezelius and Hauck (2011) show in the context of small-scale fishery how the limit between subsistence and economic activities brings out varying compliance motivations and that the non-respect of rules is considered

legitimate for subsistence activities but is culturally condemned if it's to make money. This aspect cannot be ignored in the case of fire. The difference between small-scale and large-scale farming is rarely taken into account. Communication campaigns were directed only towards small-scale farmers, implicitly recognizing that large-scale farmers do not lack information but have economic motives for their practices (Costa, 2006). It would be important to better understand these varying motivations to adapt policies to the different types of farmers.

Moreover, fire presents particularities which make it difficult to approach from usual compliance theories, which identify the person responsible for an undesirable behavior. Liability and responsibility issues make it difficult to control the effort in limiting fire, or capacity of the communities to monitor and sanction risky behaviors (Barlow 2012, Carmenta 2013). In our experience in the field, we have often met farmers who declare they would like more external control related to fire accidents, as they are incapable of having internal control on such a tricky issue. This shows well that there is a need to explore policy mixes which can combine authority, incentives and awareness building.

5.3. Towards more participative approaches to fire policy

One of the criticisms made to command-and-control or conventional market-incentive policies is that they generally work best under constant conditions and do little to promote learning dynamics which are fundamental to bring about change (Boyd 2008, Voss & Bornemann 2011). By contrast, pro-active policies for empowerment, capacity building and innovation can help create the space for new knowledge and perceptions to emerge, for social interaction, and social learning (Leeuwis & Pyburn 2002). Whilst nobody can be "complied to learn", such learning processes can stimulate motivations linked to an awareness of a need to change, willingness and ability to participate in this change (Marshall & Marshall 2007).

We consider that the stake is not only to develop better knowledge of fire or of farmer motivations, but integrating the construction of such knowledge in a process so it can be mobilized by the different stakeholders and translated into adequate policies (Coudel et al. 2011). Several studies show concern regarding the unilateral direction of information and the lack of space for dialogue on the fire issue (Carmenta 2013, Sorrensen 2009, Brondizio et Moran, 2008). Farmer organizations ought to be involved in defining the rules and stop being treated only as targets. Instead of producing panacea rules (Ostrom 2007) and "best practices", it seems important to discuss principles of action which would orient the type of action to take in a given situation (Röling & Wagemakers 1998). Based on such principles, monitoring and information systems could be adapted to local realities, instead of

perpetuating the cultural divide between the scientific lexicon and the farmers pratices (Brondizio et Moran 2008).

It seems urgent to develop prospective and participative approaches in which ecological, agronomical and social points of view could be discussed among researchers and with different stakeholders (farmers, extension agents, policy makers, etc.), to define policies which would take into account the complexity of the fire issue and stimulate adaptation. In fact, this literature analysis was a prelude to a prospective process we intend to carry out in the coming year. To support collective reflection in relation to complex socioecological systems, some approaches have been developed combining participative simulation and scenario building, such as the Companion Modeling approach (http://www.commod.fr, Etienne 2010). These instruments can enable to mediate among different stakeholders and favor exchange of perceptions, appropriation of knowledge and discussion of collective scenarios (Becu et al. 2008). The Commod methodology aims at revealing elements that wouldn't emerge in conventional interviews, enabling the stakeholders to take some distance from reality and debate issues which may be conflictual or taboo. We hope this process will encourage discussion about different components of current institutional arrangements and enable to explore possibilities to limit fire risk, in particular by revealing motivations and discussing possibilities of different policy mixes.

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