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Smallholders' collective action and fire risk in the Brazilian Amazon

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Introduction

While deforestation pace in the Brazilian Amazon has slow down over the last decade, many studies have pointed to an alarming increase in fire occurrence even in areas where deforestation is decreasing (Aragao and Shimabukuro, 2010). Fires, which are mainly of agricultural origin (Diaz *et al.*, 2002), harm the natural ecosystems, jeopardize the environmental services they provide and damage natural resources the communities use (Ferreira *et al.*, 2012). Fires are also an important social issue, as they destroy agricultural production systems and infrastructures, and cause local populations to suffer from serious economic losses (Cochrane, 2003; de Mendonça *et al.*, 2004; Diaz *et al.*, 2002; Nepstad *et al.*, 1999).

Traditionally, smallholders burn plots of land surrounded by moist forest where few or no fire control measures are needed because non-degraded forests are not easily flammable (Cochrane, 2000; Nepstad *et al.*, 1999). However, because of forest degradation due to logging activities, extreme weather events (e.g. El Niño), climate change, and previous fires, forests and surrounding landscapes have become increasingly flammable (Nepstad *et al.*, 1999; Soares-Filho *et al.*, 2012). Unless fire control measures are implemented, there is a high risk of fire spreading out from agricultural areas and accidentally burning surrounding areas.

Responsibility for controlling wildfire risk is generally considered to have both public and private components, because actors all contribute to this risk and to varying degrees share the consequences of destructive outcome (Winter and Fried, 2000). As such, fire control is a typical collective action dilemma: farmers would all benefit from fire control, but such control has an associated cost, making it unlikely that any farmer individually will control it unless an effective coordination mechanism will be operating. The unwillingness of one farmer to invest in fire control may result in damaging neighboring properties (Bowman *et al.*, 2008; Nepstad *et al.*, 1999; Simmons *et al.*, 2004). Nonetheless, very few studies have investigated fire control, and among them, only two framed this issue as a problem of collective action (Carmenta *et al.*, 2013; Simmons *et al.*, 2004). These studies addressed the importance of commitment toward community and social capital in

limiting fire contagion, referring to seminal works on natural resources management (Agrawal and Ostrom, 2001; Ostrom, 2000a), but the results regarding possible links between social organization and fire control were not conclusive (Carmenta *et al.*, 2011; Simmons *et al.*, 2004).

Although much literature has explored the conditions that explain the success of already existing collective actions in the management of natural resources (Ostrom, 2009), grasping what determines the emergence of new collective norms and rules remains a big challenge for social sciences, especially if explicit norms have not yet emerged and collective action is not observable (Ostrom, 2010). Even when engaging in collective action may appear to be a win-win solution, individual choices depend on how each actor perceives the situation, and this will determine the outcome of collective action (Brewer and Kramer, 1986). The complexity of the interaction within a socio-ecological-system, the cognitive limits of actors and communication difficulties challenge the emergence of a sufficient reason to engage in collective action (Bromley, 2006; Bromley, 2008).

In this work we analyze what brings smallholders to control fire and whether collective action has a role in this fire control. We argue that a successful collective action is an important determinant of fire control. Moreover we discuss to what extent collective action may contribute to solve the fire control problem.

Chapter 1 presents the general context by providing an overview of existing literature related to fire use and fire control and inform on the purpose and hypothesis of this work.

Chapter 2 presents the three methods of analysis used in this study and how they are interlinked. A review of collective action thinking provides the starting point to reflect on the relevance of new questions relating to collective action, and to the need for new tools. The methodological choice of mixed method triangulation takes into account the need for qualitative and quantitative analyses. We discuss the use of in depth interviews and Q methodology coupled with econometric analysis. An epistemological ground to ensure methodological coherence is provided. A methodological framework shows how this procedure is consistent with the objective of studying collective action as a potential solution.

Chapter 3 analyses the role of institutions and the local context through a qualitative enquiry conducted in two municipalities of the Easter Amazon, Paragominas and Ipixuna do Pará, in the so called Arc of Deforestation. By means of a collective action framework we identify the most important factors affecting collective action, how local institutions affect fire control and how the latter relates with production and conflicts in the communities. We also link local

policies and smallholder perceptions on fire control. Our study shows that the policies developed by Ipixuna do Pará seem to have provided an important basis for fire control among smallholders.

Chapter 4 provide a formalization of the main issues highlighted in Chapter 1 and 3. First we provide a description of the strategic interaction arising in fire control choice reformulating Shafran's (2008) argument of interdependent choice in setting fire defensible space around houses at the wild-urban interface. Secondly we describe a lock-in situation in which fire risk constrains over the choice of crops and may impede a transition out of fire use. Thirdly, we reformulate Bowman *et al.* (2008) model of the investment in firebreaks to understand the consequences of endogenous risk and fire sensitiveness of different crops on the optimal investment in fire control measures. Based on this formalization, an empirical model is estimated using data collected by a large project named Sustainable Amazon Network (*Rede Amazonia Sustentavel*). Along with the variables already reported in the literature we estimate the impact of trust and social capital on five fire control measures.

In Chapter 5 we analyse how the perception of fire risk and of its controllability affects the likelihood of collective action. Framing fire risk involves understanding the characteristics of the ecological system (Nepstad *et al.*, 1999) but also the farmers' practices, social representations and social relations (Carmenta *et al.*, 2013). Thus, depending on the individual's environment, social ties and experience, perceptions will differ as well as preferences regarding the type of governance which could improve fire control. To understand how individuals frame this risk and the effectiveness of collective action to control it, we used the Q-method (Brown, 1980; Barry and Proops, 1999; Ockell, 2008) to elicit actors' mental models. We found four distinct discourses showing substantial heterogeneity of views about fire use, fire risk, and norms about fire prevention and control, but consistent beliefs that fire control is essential. This suggests that clear fire control norms have not yet emerged and that there are competing logics. The results of Q methodology show also that a high-perceived risk limits collective action.

Finally Chapter 6 summarizes the main findings, discusses policy implications and identifies future research issues.

Chapter 1

Fire risk and smallholders in the Brazilian Amazon

1.1. Introduction

Amazon is the largest forest in the world, and hosts one of the greatest agricultural colonization frontiers (Assunção *et al.*, 2012; Nepstad *et al.*, 1999). However, despite the great economic development of the last two decades, the poverty headcount in the Brazilian Amazon region is still constant and definitely higher than in the rest of the country. Between 1990 and 2005 poverty rate was still 45% while it fell in the rest of the country from 42% to 31% (Celentano *et al.*, 2012). Moreover the region is now confronted to ample environmental problems. In 2007 the International Panel on Climate Change stated that 17% of world green-house gases emissions were caused by deforestation and biomass decomposition (Susan, 2007), 75% of Brazilian CO₂ emission is being caused by deforestation (Barreto and Araujo, 2012). But while after severe command and control policies deforestation has fallen by 80% since 2004, fires are still increasing, also in reduced deforestation areas (Aragao and Shimabukuro, 2010), threatening the benefits from avoided deforestation (Barlow *et al.*, 2012). The trend is probably destined to an upward sloping path since recent reports indicate an increasing risk of drought and risk of “mega-fires” (Aragao *et al.*, 2008; Carr *et al.*, 2009; Malhi *et al.*, 2009; Williams *et al.*, 2011). On the one hand after the big fires of 1998 controlling forest fire become a priority in the national and international policy arena (Ariaga, 2002; Carmenta *et al.*, 2013); on the other, little knowledge exists about the causes of fires (Carmenta *et al.*, 2011; Carmenta *et al.*, 2013), and the increasing threat of wildfire indicate that current policy measures are failing in addressing this issue (Aldersley *et al.*, 2011; Alencar *et al.*, 2004).

1.2. Deforestation edges and fires

1.2.1. The edge of deforestation

After Kyoto agreements in 1997 the issue of carbon emissions has become much debated at the international level. Reducing deforestation became a political priority for Brazil: an internal pressure to deforestation reduction emerged due to the disruptive effects of extreme climatic events and the decline in the belief that deforestation was essential to growth (Barreto and Araujo, 2012; Sparovek *et al.*, 2012).

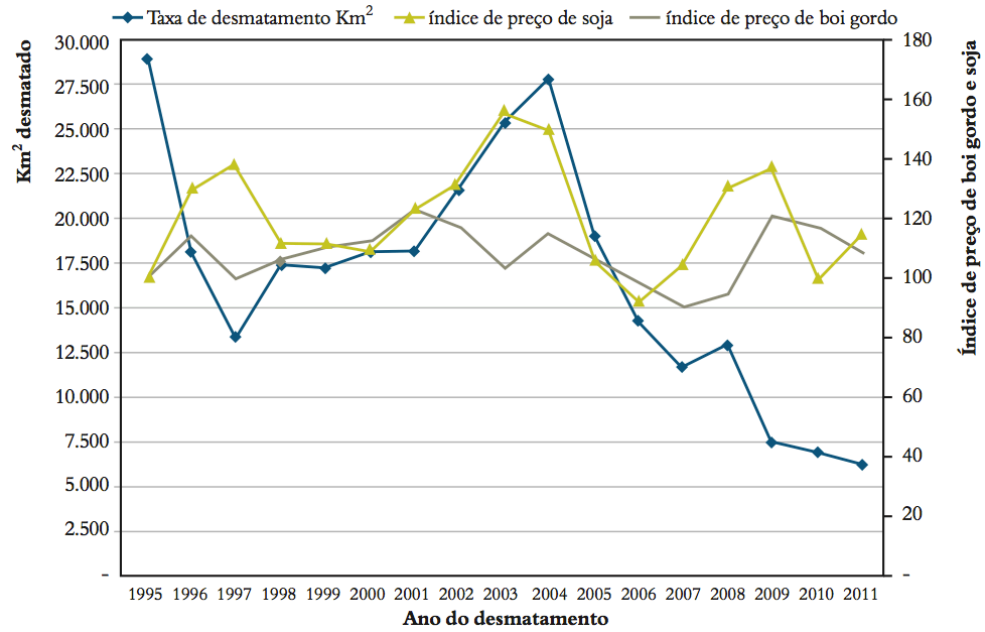
In response to this pressure policy makers started thinking about deforestation reduction as an achievable goal (Sorrensen, 2009). Since 2000 Brazil greatly increased the area of Indigenous Reserves and Protected Areas (Soares-Filho *et al.*, 2010; Toni, 2011). In 2004 a new policy bent took place in response to a new deforestation peak (figure 1.1). A new action plan (PPCDAm) solved was launched to coordinate different policies and thus try to solve a problem of contradicting policies among federal, country and municipal level; and the upgrade in satellite monitoring technique (Brito and Barreto, 2011), along with police and army control intensification, allowed a more effective command and control policy implementation (Assunção *et al.*, 2012; Barreto and Araujo, 2012). In 2007 another deforestation peak occurred following cattle and soy price increase (fig. 1). A new PPCDAm phase, named “Arco de Fogo” (Fire Arc), engaged in strong measures of command and control against big cattle producers, including also strong economic disincentives regarding credit and market access: a black list of most deforesting municipalities was created in order to prioritize controls, credit restrictions and land regularization (Assunção *et al.*, 2012; Barreto and Araujo, 2012). Since 2006 a soy moratorium and a beef embargo took place in order to make producers as well as all the production chain responsible (Barreto and Araujo, 2012; Nepstad *et al.*, 2009).

In 2009, as part of its policy against climate change, Brazil voluntarily committed to reduce deforestation rate by 80% by 2020 with respect to an average baseline of the 1996-2005 period (Law n°. 12.187/2009 and Decree n°. 7.390/2010). Following the *Arco de Fogo* operation, by 2012 Brazil had managed to reduced deforestation by 76% of the ultimate goal of 2020 (INPE 2013).

Brazilian policies have thus become an example of efficacy and efficiency in reducing deforestation rapidly in a difficult context. Figure 1.1 shows how policies initially took advantage of the soy and beef price fall, and then, with the second PPCDAm phase, broke the vicious causality among world agricultural prices and

deforestation (Assunção *et al.*, 2012). Nevertheless market led policies had the side effect to leave behind smallholders in this transition, whose motivations are more related with social and livelihood issues (Coudel *et al.*, 2012).

Figure 1.1: Deforestation trend and the effect of policies on correlation with soy and beef prices.



Source: (Barreto and Araujo, 2012)

1.2.2. The surge of fires

While deforestation in the Brazilian Amazon has decreased by more than 80% since 2004, many studies have pointed to an alarming increase in fire occurrence even in areas where deforestation is decreasing (Aragao and Shimabukuro, 2010). Fires, which are mainly of agricultural origin (Diaz *et al.*, 2002), harm the natural ecosystems, jeopardize the environmental services they provide and damage natural resources the communities use (Figure 1.2) (Ferreira *et al.*, 2012). Fires are also an important social issue, as they destroy agricultural production systems and infrastructures, and cause local populations to suffer from serious economic losses (Cochrane, 2003; de Mendonça *et al.*, 2004; Diaz *et al.*, 2002; Nepstad *et al.*, 1999). Moreover forest degradation caused by wildfires has the additional effect of reducing evapotranspiration, reducing forest cover, reducing rains and increasing flammability at the local level starting a vicious cycle (Nepstad *et al.*, 2001; Nobre *et al.*, 1991; Shukla *et al.*, 1990). Indeed unless extreme (but frequent)

conditions happen, like the El Niño event, moist forest is not flammable (Simmons *et al.*, 2004; Wetzzel and Omi, 1991). But after logging disturbance forest became vulnerable to raster fires, starting the following vicious cycle: woodsman open roads and implement selective cut in order to extract trees, this activity increase tree mortality, reduce humidity, and increase flammability, driving up to crown fires removing forest cover, the most ecologically disruptive fire event (Barlow *et al.*, 2012; Nepstad *et al.*, 1999).

Figure 1.2: Raster forest fire originating from pasture renewal



Amazonian smallholders and fire use

Fire is widely used in agriculture in tropical regions, making it difficult to prohibit its use (Sorrensen, 2009). Fire is a “voluntary worker”, effective in clearing land for pastures and crops, control weeds and fertilize soil at a low cost, (Pollini, 2009; Siegert *et al.*, 2001). Agricultural populations in the Amazon use fire in primary forests in order to clear and fertilize soil at a low cost and in deforested lands to clear pastures or to prepare land for crops. Slash and burn in the Amazon is an important agriculture cost-saving technique: the livelihood of smallholders strongly depends on it, mainly because of lack of acceptable alternatives (Coudel

et al., 2013; Mistry and Bizerril, 2011; Sorrensen, 2009). Fire is also a culturally embedded practice, since it is a fundamental part of the swidden cycle of *roça* (Carmenta *et al.*, 2013), the agricultural plot dedicated to annual cultures. *roça* appear to cover an irreplaceable role in familiar agriculture because it traditionally provides the main part of the everyday meal: rice, beans, manioc flour and corn (Jackson and al., 2007; LIMA, 2005). As they are the basis of traditional livelihoods, *roça* play an important role in improving resilience to external shocks (Adams, 2009; Parker, 1989).

Recently, environmental policies have supported intensification of land use by large-scale landowners (Barreto and Araujo, 2012), but have done little to target smallholders whose livelihoods still largely depend on agriculture and in particular on the use of slash and burn: different alternatives have been suggested to avoid using fire, including mulching or fertilizers (Denich *et al.*, 2004; Denich *et al.*, 2005; Kato *et al.*, 1999), or other cultivation systems, based on perennial crops (Hoch *et al.*, 2012). However, given the lack of effective complementary measures regarding market access and technical assistance (Hoch *et al.*, 2012; Pollini, 2009; Sorrensen, 2009), these options are seldom viable (Börner *et al.*, 2007; Villemaine *et al.*, 2012), and fire is still the most cost-effective technique (Pollini, 2009). Moreover, in fire-prone areas, investing in costly alternatives like perennials appears to be discouraged by the risk of destruction by accidental fires (Nepstad *et al.*, 2001; Nepstad *et al.*, 1999; Pokorny *et al.*, 2012). A transition out of slash and burn by smallholders is not likely to occur in the short term (Carr *et al.*, 2009).

The origin of fires

The practice of swidden fire either by Amazonian smallholder and big landholders is largely spread as an essential and cost-effective agricultural technique with a high cultural value. However swidden fires are responsible for a multiplicity of ignition sources and may cause accidental wildfires, but the two types of fires are distinct events. Indeed fire risk does not derive directly from fire use, but from the lack of adequate fire control. However wild and swidden fires have been confused in literature for a long time (Carmenta *et al.*, 2011), leading to stigmatization and misunderstanding about fire practices and wildfire causes (Coudel *et al.*, 2013). Since the nineties hotspots and scar images obtained through satellite monitoring are the main tool to study fires, but satellites do not reveal the motivation that induce to start a fire nor whether a fire is a voluntary or an accidental one (Sorrensen, 2009). Based on a large-n literature review Carmenta *et al.* (2011)

showed that only few field studies exist about fires in the Amazon, and that little knowledge exists about their causes. Fire episodes are usually associated to high anthropic pressure, logging, agricultural activity and increasing forest flammability (Davidson *et al.*, 2012; Sorrensen, 2009; Uhl and Buschbacher, 1985). But few or no studies deepened actor habits, rationale and motivations. Moreover studies concerned fires for opening and maintaining pastures by big landholders (Carmenta *et al.* 2011). On the one hand literature from ecology, agronomy and social sciences provided wide evidences of the disaster caused by fires, pushing further research towards alternatives to fire use and radicalizing policies to against fire use (Coudel *et al.*, 2013). On the other, however, there is little research about the origins of fires in the Amazon, and there is still no agreement on the conditions under which fire use is effectively more environmental harmful than intensive farming (Chazdon, 2008; Omeja *et al.*, 2012). The sociologist Ulrich Beck (1992) claims that human attention is biased toward the effects of risky events more than on the *causes and symptoms* of the risk. This is the case with respect to fires in the Amazon: the International and Brazilian discourses around deforestation and fire drove toward an excessive faith in technological advancement on remote sensing techniques. But geographical data, even if crossed with socio-demographic space wide data (as demographic density), has no capacity to reveal any insight of the *causes and symptoms* of fire use and fire control (Hayes and Rajão, 2011). That is why there is a strong need for field based studies (Carmenta *et al.*, 2011) about the causes of fires.

1.3. Fire control and smallholders

Lack of fire control is an important driver of forest degradation, a risk for neighboring properties and protected areas and a disincentive to investment on properties (Barlow *et al.*, 2012; Cochrane, 2003; Cochrane *et al.*, 1999; Davidson *et al.*, 2012; Mistry and Bizerril, 2011; Nepstad *et al.*, 1999; Pokorny *et al.*, 2012; Sorrensen, 2009). Pokorny *et al.* (2012) and de Mendonça *et al.* (2004) found respectively that 66% and 88% of the interviewed producers experienced damages caused by fire. Indeed local farmers are probably the most interested agents in controlling fire as they are directly damaged by uncontrolled fire (Barlow *et al.*, 2012; Bowman *et al.*, 2008; Cochrane, 2003; Davidson *et al.*, 2012; de Mendonça *et al.*, 2004; Mistry, 1998; Nepstad *et al.*, 1999; Pokorny *et al.*, 2012; Sorrensen, 2009).

1.3.1. Fire control as compliance to the law

Use of fire in general for agricultural and cattle breeding purposes is tolerated by the federal law, conditioned on a licensing system organized by the environmental secretary of each state (art. 27 Forest Code: Federal Law 4771/65). Country or municipal level can apply stricter regulation, for instance, totally prohibiting its use.

The Brazilian Forest Code already makes burning without specific precaution illegal (Article 22, Forest Code/1934), require licences to use fire (Article 27), and makes some fire control measures compulsory (Presidential Decree 2661/98; Portaria IBAMA 94/98; Presidential Decree 3179/98). Although the risk of high fines and penalties up to imprisonment compliance is still low, and fires tend to prevail.

Since satellite data are not sufficiently disaggregated¹ to be reliable for fire originating in small plots (Nepstad *et al.*, 1999) it is not possible to estimate the relative impact of smallholders and big landholders action on fire risk. However the formers are more dependent and less prone to abandon fire practices, and the cost of setting fire control measures is higher for them than for big landholders (Nepstad *et al.*, 1999).

On the one hand big producers are addressed by several policies: controlled through quasi-instant satellite monitoring data, they must hold a special land entitlement accounting for forest surface on the property (CAR) to access markets (Barreto and Araujo, 2012); moreover if using fire, they need a fire licensing system and usually have the means to control fires (Nepstad *et al.*, 1999). On the other hand, smallholders face higher fire control costs, and are less moved by current policies: implementation of controls, fines and licensing toward smallholders is much less cost-effective for the government because it would probably need much more resources devoted to enforcement activities (Börner *et al.*, 2011) as property are numerous and distributed. Smallholder's compliance is difficult to be achieved also because current policy setting delegitimizes slash and burn, considered as a primitive practice, and no concrete alternatives are furnished (Carmenta *et al.*, 2013; Coudel *et al.*, 2013).

After the mega fire devastating 36.000 km² of forest in Roraima between February and March of 1998, ProArco, a ten-year urgency program, was launched to improve fire control. It included a large activity of dissemination competences

¹ The pixel resolution in the latest deforestation and fire maps is of one square kilometers (<http://modis.gsfc.nasa.gov/>), and fires are individuated only if exceeds a size of 1mx30m (INPE 2012)

for fire control using an educational and participatory approaches (Nepstad *et al.*, 1999; Sorrensen, 2009). The program was carried on by the Minister of the Environment and by IBAMA, the National Agency for the Environment. Notions about fire management were largely communicated through radio, television and in printed guides distributed by NGOs and the government technical assistance (Costa, 2004).

The fire control measures disseminated by ProArco are not limited to the construction of physical barriers such as firebreaks, but also concern with meteorological and socio-institutional measures (Carmenta, 2013). Adequate weather conditions relate to humidity, wind intensity and direction. Farmers should wait for the first rains of the season to increase humidity of the surrounding forest, and light fires only in the late hours of the days, usually colder and less windy. In order to avoid high and fast flames backfire is also suggested. Socio-institutional measures relates to the positioning of the area burnt with respect to other plots, agreement in the community with respect to the time and the location of fires, a minimum of four persons monitoring the burn, and neighbors alert before burning, all that in order to increase vigilance on burnt and avoid fire spread in the adjacent properties. Moreover the farmer must look after the fire for as long as it burns and carry water in site.

These and many other norms and praxis have been studied and suggested to smallholders (Carvalho *et al.*, 2007; Costa, 2006; Mistry, 1998), and although NGO-led programs have been shown to be successful locally (Carvalho *et al.*, 2002; Nepstad *et al.*, 1999), other studies show that the adoption of these measures is relatively limited (Costa, 2004), partly because they do not match local knowledge (Carmenta *et al.*, 2013; Mistry, 1998), or simply because they are too expensive. Nepstad *et al.* (1999) estimated that the cost of building firebreaks for a small producer can reach up to 61% of his profits.

Carmenta (2013) evidenced a policy-practice disparity due to the miscomprehension of local technical capacities, local requirement for a “good burn” and culturally inappropriate rules: law requires to built a 2-6 meters wide firebreak around the burn area, this is nearly unfeasible with local technical capacity and resource availability. Moreover farmers lack confidence in firebreaks effectiveness because of careless neighbors and the wind carrying sparks from afar fires. Burning in cooler hours without wind does not lead to a “good burn” since a lot of fuel stand unburned and more work is needed to chop logs and to root out unwanted weeds and wild plants after fires and during the year. For the same reason lighting fire against the wind is not practiced. However fire is usually lighted on all the sides

of a plot, originating a kind of backfire. The major cost related to the compliance with socio-institutional measures relates to the unpredictability of weather events. It is rare that people get the license to use fire or even alert neighbors formally at least 3 days in advance, as required by law, because this would imply the ability to foresee the optimal weather condition to burn. Moreover fire contagion events are not perceived as a criminal act: in the sample of Carmenta (2013) nobody ever asked for compensation for damages or reported careless neighbors.

Finding a solution to fires need to overcome the policy-practice gap. While fire is conceived as a risk and policies are oriented towards its elimination, fire is still a primary livelihood tool for the rural population of the Amazon region (Carmenta, 2013; Coudel *et al.*, 2013). Policy panaceas are advised against (Ostrom *et al.*, 2007), and a clear understanding of fire control choice and of fire management practices is of crucial importance to ensure local livelihood as well as policy goals on fire management (Mistry and Bizerill 2011, Carvalho *et al.*, 2002; Costa, 2006; Nepstad *et al.*, 1999).

1.3.2. Fire control as a risk mitigation strategy: the limits of current literature

As far as my knowledge goes, only three models try to explain the factors affecting the decision to set fire control measures, discussed in Bowman *et al.* (2008), Carmenta *et al.* (2013) and Simmons *et al.* (2004). Beyond them, Shafran (2008) offer an interesting discussion of the positive externalities arising in fire management with respect to the decision to set a defensible space around houses at the wild urban interface, and the mechanism is close to the fire control choice. Morello (2013) looks for the existence of externalities and neighborhood effects in land use decision.

Bowman *et al.* (2008) built a constrained household model and consider that the allocation of labor to firebreaks depends on the opportunity cost of labor and land allocated to firebreaks compared to the protective effect of firebreaks on crops and forest providing non timber forest products. The key hypothesis of this model is that fire risk is exogenous to the household, and that thus there are no externalities in the decision to allocate labor to clear firebreaks. The empirical model consequent to this formalization show that the shadow wage of planting labor, the price of manioc flour and the hunting activities are good predictor of the engagement in fire prevention and of the labor allocated to firebreaks. Moreover a likelihood ratio test provides evidence that household feature are far less important than the economic variables. The hypothesis of exogenous fire

risk is the most important limitation of both the theoretical and the empirical models, indeed the perceived effectiveness of the control also influence whether individuals believe it is worth taking protective action or not (Slovic, 1987). Even when farmers have an individual interest in controlling fire to avoid damage to their own assets, they may not make this costly investment if there is a risk of fire contagion from adjacent properties. Thus, assuming fire risk as an endogenous variable, the choice of implementing fire control measures depends also on the success of collective action at the local level (Cammelli and Coudel, 2013).

Few studies have investigated the externalities involved in fire control and they mainly showed that agreement within a community regarding fire is rare, if not inexistent (Carmenta *et al.*, 2013; Mistry, 1998). Morello (2013) shows that the externality exists and that high transaction costs impede Coasean bargain. While the sample of Carmenta (2013) (n=156) shows that no single household received compensations for the damages occurred, and that lack of fire control are not perceived as any of the other hurting action demanding compensation, some studies reported evidence of cooperation in traditional communities and more recent settlements (Bowman *et al.*, 2008; Brondizio and Moran, 2008; Toniolo, 2004), which may be explained by a difference in agricultural practices and market access but also by stricter social relations and organizational capacity in the traditional communities.

Simmons *et al.* (2004) sought to identify the relationship between social capital (defined as belonging to a political organization) and the occurrence of fires. Carmenta *et al.* (2013) built an index of commitment toward the community (a combination of birth in the community, migration, number of years lived in the community and number of organizations) and linked it to the adoption of fire control measures. Neither author found a significant correlation between the two variables.

Why do they fail in determining social capital or collective action as fire control predictors?

Possible problems relate to: proxies' definition, mismatch between the level of enquiry and the level of collective action, wrong definition of the mechanisms operating, and understanding of institution involved.

Defining, observing and measuring social capital and collective action is always challenging, both studies refer to the same seminal strand of literature on social capital and role of communities: Agrawal and Gibson (1999); Dasgupta and Serageldin (2000); Ostrom *et al.* (1993) considering it as providing sufficient incentives to set fire control measures. However there is no clear explanation of

why belonging to a political organization should relate to the social capital evoked in this strand of literature. Social capital, social control and collective action may operate at different spatial and organizational scale (Poteete and Ostrom, 2004): at the neighbors level, community level, municipality or even higher level; or to different organizational level: member of a believer community, an association etc. Moreover for any definition and every level of analysis social capital may affect incentives to set fire control measures through possible alternatives channels. Those issues, as in many other studies on collective action (Ishihara and Pascual, 2009), have not been explored in any of the two studies. For this reason the two works can't be considered to bring conclusive evidence against social capital as a determinant of fire control.

1.4. Statement of purpose

In this study we support the thesis that fire risk is, to some degree, endogenous to the community or to the neighborhood. Fire control produce a positive externality (in terms of reduced risk), understanding the fire control choice need to take into account not only direct costs and cultural appropriateness but also the interdependency that arise in fire management, and the implication for collective action at the local level. We define collective action as the cooperation process to provide a norm for fire control: a public good. The direct output of collective action (the norm) is not observable, but the outcome, setting fire control measure, can be observed and measured. Trust and social capital are the main indicator that a collective action process is occurring.

Besides assessing the relative importance of collective action as a predictor of fire prone behaviour (Chapter 4), we aim explaining why and how this mechanism operates (Chapter 3, 5), and to provide useful information to improve national and local policies addressing fires and forest conservation.

Chapter 2

A mixed method approach to study collective action

2.1. Introduction

Studying collective action is challenging because of specific difficulties related to the definition of the phenomenon, the unit of analysis (Poteete and Ostrom, 2004), the number of variables involved (Agrawal, 2001) and the difficulties to isolate and define causal relationships (Gibson *et al.*, 2005; Ostrom, 2010). Indeed a coherent theory linking all structural variables affecting collective action has not been designed yet (Ostrom, 2010). Collective action has a lot to do with uncertainty and beliefs (Ostrom, 2000a), and an analysis of collective action needs to take these dimensions into account. The main justification of this Chapter is that the usual positivistic approach used in economics and the related methods have proven insufficient in studying collective action (Poteete *et al.*, 2010), and a new approach is needed. We chose to start a reflection in this direction adopting a triangulation methodology and designing a framework to discuss the choice of a methodology consistent with the goals of this study.

This methodological framework is largely inspired by a realist and pragmatic methodological approach in the sense of Bromley (2008): seeking reasons, and not justifications to the behavior of actors. Human beings are immersed in an uncertain reality and somehow undetermined future (Hardin, 2003), where they are not just seeking an optimal choice since the set of choices is not already given. They are probably seeking beliefs in order to act on a reasonable base, they are probably asking: “what to do? and, why?”. Individuals do not answer this question in solitude, but within their epistemic and hermeneutic communities and traditions (Hodgson, 2007a, b). For this reason a lot of attention is given to the

institutional and relational context which leads to the definition of the situation.

The analysis will seek motivations and not preferences. While the revealed preference theory assume consistency between action and preferences (Sen, 1977; Vatn, 2005), analysing motivations of actions (instead of just reducing choices to an utility maximization problem) account for the commitment problem to be an object of study rather than an assumption.

Motivations are not a property of objects or events, but pertain to statements on objects or events. The decision of what is true or not is a collaborative and evolutionary matter (Bromley, 2008; Johnson and Onwuegbuzie, 2004). This ontological stance constrains upon the use of an only method (out of positivism, that assume an objective reality and its cognoscibility by one only scientific method), imposing a pluralism of methods. This multiple method approach is inspired by Downward and Mearman (2007) mixed-method triangulation as a manifestation of retroduction¹ in economic research. An alternative to mere deductive or inductive reasoning is to overcome the use of a method in a disciplinary sense and to mix qualitative and quantitative approaches.

A review of collective action theory provides the starting point to reflect on the relevance of new questions relating to collective action, and to the need for new tools. The methodological choice of mixed method triangulation takes into account the need for both qualitative data and statistical analysis. An epistemological ground to ensure methodological coherence is provided. Finally a methodological framework is drawn to show that triangulation is consistent with the objective of this work to study collective action with both positive and normative purposes.

2.2. The study of an interdependent choice

2.2.1. The conventional paradigm

The conventional paradigm of collective action is made up of three reinforcing theories, all based on rational choice analysis: Hardin's tragedy of the commons, the prisoner dilemma (and other game theory models), and social dilemmas (Poteete *et al.*, 2010).

For Hardin (1982:95) the tragedy of the commons (rival but not excludable goods) is inevitable since:

'Each man is locked into a system that compels him to increase his

¹ 'Mode of inference in which events are explained by postulating (and identifying) mechanisms which are capable of producing them' (Sayer, 1992:107 apud Downward and Mearman 2007).

herd without limit in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons’.

This pessimistic view is consistent with the outcome of the Prisoner Dilemma and other non cooperative games in which an inefficient Nash equilibrium is often preferred to a more efficient cooperative equilibrium. Following this theory, cooperation is rarely achieved because it involves a social dilemma in which maximizing short run individual benefit leads to an inefficient suboptimal outcome (Lichbach, 1996; Schelling, 1978). Even in repeated game, by backward induction the final outcome is always zero cooperation (Luce and Raiffa, 1957). Olson (1965) supports three main determinants of collective action: group size, selective incentives and heterogeneity of intents. Self organized groups do not provide sufficient individual benefits to incentivize agents to produce a public or common good: in absence of an “entrepreneur” particularly interested in producing the public good and setting selective incentives, individuals will free ride, failing to achieve cooperation.

These theories are self-reinforcing and up to the 80’s were not questioned. Poteete *et al.* (2010) state that they are theories of ‘collective inaction’ rather than theories of collective action, as they fail in explaining the variance between groups successfully managing a common or producing a public good. In fact in successive years, case studies started reporting successful cases observed in many region of the world, and experimental research found unexpectedly high levels of cooperation (Poteete *et al.*, 2010). This led to a refinement of traditional theory.

Clark (2006) enlightens how theories belonging to the conventional paradigm rely on strong assumptions relating to actor characterization and the definition of the situation. Actors are homogeneous, have complete information about the environment and act independently one of each other as if they were maximizing their short run self-interest. The assumption of complete information especially contrasts with the structural uncertainty that characterizes the interaction between human and ecological system (Brondizio and Moran, 2008). A better characterization of agency and the understanding of the role of institutions is key in this respect (Bromley, 2006; Vatn, 2005). Many authors noticed how modifying standard assumptions could bring about many opportunities for successful collective action to occur (Poteete *et al.*, 2010).

2.2.2. The new story and the new problems

Taking seriously these critiques, research since the 90's started considering standard game theory as too restrictive (Ostrom, 1990; Ostrom et al, 1992b) and taking advantages of evolutionary approaches; new tools were developed in this field such as laboratory experiments and more recently agent based modelling (for a complete review see Poteete *et al.* (2010)).

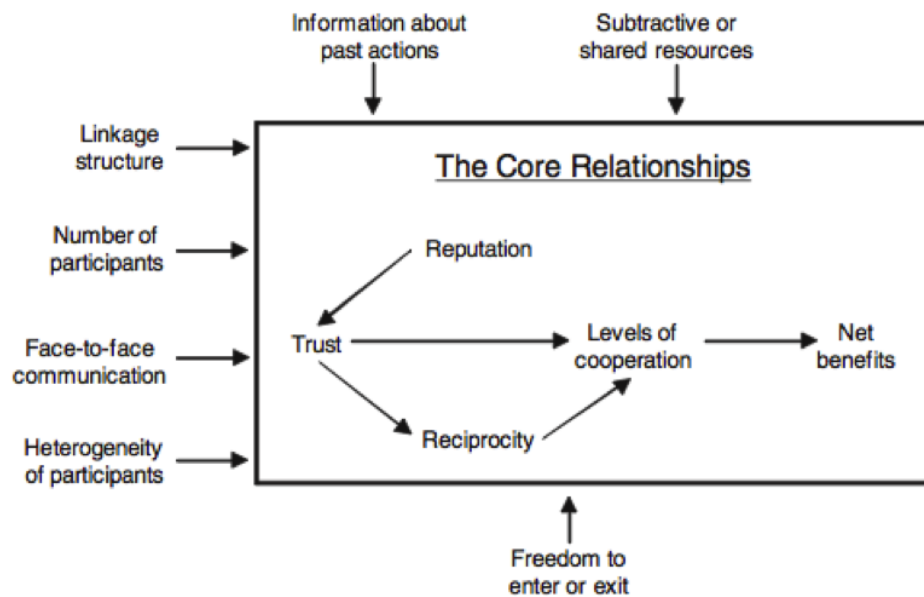
Empirical research in the field improved in quality and quantity (Ostrom, 2010), but new problems emerged. A number of small-n case studies evidenced new important variables, and thanks to the common IFRI protocol, sufficient data were collected to operate large-n analyses (Gibson *et al.*, 2005; Poteete and Ostrom, 2004).

The backdrop of this new empirical approach is that the array of factors influencing collective action skyrocketed, making it increasingly challenging to study this phenomenon, especially in complex social-ecological system (Ostrom, 2009). A review of variables found a “restraint” set of 33 variables having such an important potential influence over collective action likelihood, that any rigorous study could not omit them without adequate explanations (Agrawal, 2001). Controlling for all these variables leads to complicated data collection, research design and consume degrees of freedom. Moreover there is no agreement over the definition of variables: which is the appropriate unit of analysis, when the unit of analysis is acting collectively or not, for which purpose may it act collectively, what does affect or definitely does not affect collective action (Poteete and Ostrom, 2004). Indeed estimating a structural model of collective action is rather challenging because of selection bias, omitted variable bias and frequently missing observations (Gibson *et al.*, 2005). Moreover since more and more evidence is showing how cooperation and trust are the result of feedback process produced in iterated interaction, independence among variables cannot be considered as a reliable assumption (Poteete *et al.*, 2010) and endogeneity bias is likely to occur (Beckmann and Padmanabhan, 2009). As a partial solution, Agrawal (2001) suggests to focus on causal mechanisms, narrow chains, and not to look at all potential variables.

While empirical research is becoming more and more challenging, theoretical research is stagnating. No clear theory links the whole ‘spaghetti plate’ of variables affecting collective action. The real challenge of present collective action research is to link the structural variables affecting collective action to the core trust-reciprocity-cooperation relationship (Ostrom, 2007, 2010) (Figure 2.1).

In the end, as many argue, research on collective action is likely to be biased

Figure 2.1: The core relationship explaining collective action



Source: Ostrom (2007, p. 202).

toward the cases in which collective action is occurring and is somehow measurable (Ostrom, 2010), lagging behind the explanation of why collective action may not occur, and which stimulus may improve its likelihood. This occur because the new approach to collective action theory has been developed in opposition to the conventional theory of “collective inaction” and because few or no tools have been developed to analyse cases in which collective action is not directly observable, where collective action is not occurring or a reciprocity norm is not observable yet. Thus a further challenge is how to turn current knowledge on collective action in fields in which collective action is not directly observable, turning eventually to normative analysis to improve governance.

2.2.3. Implication for this study

The goal of this work, rather than focusing on what determines collective action, is to study if collective action is an important issue in fire control (positive, quantitative analysis), why, and how institutions may improve governance for collective action (normative, qualitative analysis). In this sense we need an operational definition of collective action and an appropriate methodological ground.

We will use a mixed method triangulation for the triple purpose of overcoming

some of the aforementioned difficulties in studying collective action, to cross-check findings and improve their persuasiveness, and to enrich the analysis with different viewpoints.

However, as we discuss hereinafter, crossing different methods in a consistent way is not an easy task and implies a common epistemological ground (Johnson and Onwuegbuzie, 2004).

2.3. The methodological choice of triangulation and the consequences for studying collective action

2.3.1. Critical realism: the epistemological bases of triangulation in economic research

Both intensive and extensive methods have strength and weaknesses, and often rely on different assumptions. Following Downward and Mearman (2007), we discuss the opportunity and the implication of a mixed method triangulation approach.

Methods are defined within ontological assumptions that are key in defining interpretation, consistency and possibilities of generalization of results. This is the field in which theories often confront each other and evolve, and that often oppose economics to other social sciences. The blind (positivist) reliance on inductive methods versus an extreme relativism of qualitative field data (interactionism), is the main example of the chiasm separating economists and anthropologists. The debate comes from the existence or not of value free observations and measurement of a phenomenon.

Pragmatic reasons ask for bridging qualitative and quantitative methods, however on contrasting ontological bases there is no possible triangulation, since both approaches refuse each other.

Positivist ontology leads to over rely on inductive reasoning, failing because at least decision criteria to build empirical tests are value judgments themselves (Popper, 1959). By opposite the main problem of a deductive or hypothetic-deductive approach is that premises fully entail conclusions. For this to be true the world should be a close system in which single causes can be isolated. In Lawson's (1997, 2003) view this is just a conflation of the object of the analysis, what he calls "epistemic fallacy".

Instrumentalism, i.e. evaluating models by the predictive capacity instead, but not for the accuracy of the world description commits epistemic fallacy as well: the phenomena under observation is confused with a set of ideas of the observer (Lawson, 1988). Le Moigne's (1995) constructivism holds against positivist and realist ontological hypothesis of an objective reality, that can be known "asymptotical" by a procedural construction of knowledge, in which the procedure of inference incurs in the problem already defined above i.e. it is not neutral, but dependent on the choice of criteria. According to the constructivist approach the nature of knowledge is a construction, made up by the interaction between phenomena and the observer and the goals of the observer.

Critical realists distinguish themselves from naïve realists criticized by constructivism in the sense that, despite assuming an intransitive dimension of knowledge independent of our understanding of the world (i.e. an objective reality), knowledge is expressed and informed by subjectivity. Critical realism acknowledges the fallibility of knowledge (Lawson, 2003; Sayer, 2000). Actually, it is because of this fallibility that mixed method triangulation and retrodution are needed to define the causes of a phenomenon (Downward and Mearman, 2007).

2.3.2. The three component of a cause

According to Downward and Mearman (2007):

‘The concept of cause in critical realism is tied to the emergence from the interaction of human agency and institutions or structures. In this regard, the motivational (or otherwise) dimension of agency needs to be elaborated, as well as the mechanisms that facilitate action, or behaviour, coupled with the relational context of that behaviour.’

Bromley (2006, 2008) insists on the importance to redefine in economics what a cause is, since the traditional inductive method of utility maximization given a set of hypothesis does not provide an explanation itself. Asking: “why?” the answer can't be “to maximize my utility”. In Schumpeter's (1961: 4) view:

‘we succeed in finding a definite causal relation between two phenomena [...] if the one which play the ‘causal’ role is non economic’.

Abduction (or retrodution) allows to come back to the real set of causes. There are no cognizable covering laws applied to reality, because we assume that society is an open system in which time and space exist (Lawson, 2003).

Both critical realists and pragmatists recognize the fallibility of knowledge due respectively, to an intransitive component of knowledge (Lawson, 2003), or to structural uncertainty (Bromley, 2008; McDermid, 2006), leading to the indeterminacy problem in social sciences (Hardin, 2003). Both schools of thought point out that the knowledge of reality is mediated by beliefs and subjectivity, and thus they must be taken into account in the analysis. Actor reasons are part of the notion of cause as well; in the words of Bromley (2008):

‘Indeterminacy is the reason we reason. [...] Pragmatism understands human choice as a process of imagining plausible outcomes in the future under several possible descriptions’.

Addressing the ‘why’ question, we cannot ignore any of the constituent elements of the notion of ‘cause’: motivations and beliefs to operate a choice and which lead to a certain definition of the situation, the institutional and the relational structure which enable or constraint action.

2.3.3. Triangulation and collective action: a summary framework to analyse collective action as a potential solution

A common ontological ground for a mixed method is needed to define the role of each method (with respect to the notion of cause), how to interpret results and how results from a single method support (or not) each other. Here we present the three methods used in this research (semi-structured interviews, econometrics and Q methodology), and we discuss how to interpret results avoiding epistemic fallacy, that is a conflation of the subject and object of research invoking covering laws.

In Chapter 3 the result of a qualitative case study explores individual motivations and institutional factors possibly affecting collective action. Results are highly dependent on the capacity to collect and to analyze data. They partly reflect the interaction between the interviewer and the interviewee. They reflect essentially the facts relating to the persons included in the sample. However by triangulation and saturation some of the results are more apt to be generalized. Indeed statistical inference is not the only way to provide generalization. Retrodution provides the base to generalize through triangulation. Retrodution takes place by crossing results from the empirical qualitative enquiry and the results of other methods. Crossing case study and large-n methods avoids conflating of

object and subject of research by individuating the results from direct observations that are strongly mediated by interaction. Moreover the results from the econometric model can be explained assuming true propositions based on direct observations. In the end some degrees of interaction between the interviewer and the interviewee operate even collecting quantitative data. Thus statistical results even when reflecting causal mechanisms cannot supply clear-cut results.

Triangulation within the case study allows establishing validity of qualitative propositions (Yin, 2009). This case study provides information to overcome several difficulties addressed in Chapter 3 related to the study of collective action. Qualitative data allows formulating grounded hypothesis about the level, the unit of analysis and the main variables involved in collective action, to formulate the right heuristics to think about the fire control problem and to define proxies.

In Chapter 4 a theoretical model is drawn and econometric models are estimated. The results of the statistical models do not validate nor invalidate the theoretical model built from a deductive process. Any causal mechanism has the same a priori probability to be true or false. Testing prediction via an econometric model commits epistemic fallacy since empirical connections do not prove any active mechanism. Indeed since society is an open system, any latent causal mechanism based on assumptions different from those of the conjectured theoretical model may operate in the statistical model with the same or with opposite signs (Downward and Mearman, 2002).

We must take extreme care in defining meaningful proxies, and consider that there is no direct connection between the ideas of the observer and the external reality, thus variables may not reflect only the desired phenomena. Crossing variables correlation and results from the qualitative enquiry exposed in Chapter 3 may support the choice for different proxies.

The aim of a theoretical model in this study is to provide an explanation for the specification of the empirical model, the estimation procedure, and to provide a hypothesis of stylized core mechanisms. Econometrics is not apt to test model predictions; instead it is suitable to measure frequencies and correlations within a sample (Downward and Mearman, 2002).

The econometric model seeks to identify the relevance of collective action with respect to other variables within the sample. In doing that there are no inductive claims nor excessive reliance on inference, nor any ambition of predictive capacity (Downward and Mearman, 2002).

In Chapter 5 we take into account for actor subjectivity. Every positivistic assumption about the cause is finally removed. The quest for mental model add

further details to the analysis, relaxing any assumption on causes and revealing actors definition of the situation. In this it elicits the feedbacks between the factors affecting choices counted in the econometric model and the institutions affecting collective action described in the case study. Moreover by analyzing this interaction it is possible to understand how institutional innovations and collective action may arise and can be maintained (Braun and Gilardi, 2006; Matthews and Selman, 2006), and in particular the effects of different definitions of the situation on beliefs. Q methodology allows studying actors subjectivity (Brown, 1980; Stephenson, 1935), and we sought to use it to elicit actors mental models.

A mixed methods approach disentangles the phenomena from many points of view addressing all the constituent elements of the notion of cause, providing ontic depth (i.e. robustness to ontological assumptions) and strengthening the persuasiveness of findings in which it provides many different pillars supporting the same hypothesis, increasing its verisimilitude (Downward and Mearman, 2007).

Chapter 3

A qualitative enquiry: addressing the role of local institutions

3.1. Introduction

In this Chapter we carry out a qualitative analysis of the reasons (in the sense of Bromley (2008)) affecting the willingness to engage in fire control or not, and the role played by institutions in the formation of these reasons. By means of a large set of semi-structured interviews we study the effects of fire contagion and its impact on production, the fire control and fire fight practices implemented by farmers and their limits, the ambiguous influence of reciprocity and market on the choice to set fire control measures and the role of community institutions. We also report a success story about the Biennial Programme of Prevention and Combat to Forest Fires of the municipality of Ipixuna do Pará.

3.2. Collective action, compliance and institutions: a theoretical framework

In this part, we outline a theoretical framework based on collective action literature, adding some insights from compliance theory, neo institutional theory of motivational and institutional crowding out and from geographical economics.

3.2.1. Modern theory of collective action.

Decades of theoretical and empirical research found several variables affecting behaviour in interdependent choices (Ostrom, 2010; Poteete *et al.*, 2010; Poteete and Ostrom, 2004). However there is no clear link between those structural

variables and the core mechanism based on reciprocity, trust and cooperation (Poteete *et al.*, 2010). Causal mechanisms change according to the theoretical assumptions underlying each theory. Theory is particularly sensitive to assumptions relating to degrees of perfect and complete information, uncertainty and indeterminacy, bounded or perfect rationality and methodological individualism. As already discussed in Chapter 2, empirical finding from experimental and non experimental games provided evidence that assumptions about complete and perfect information and of close social system are too strong to analyse collective action dynamics, especially in the field of natural resource management (Ostrom, 2008; Ostrom, 2009). Indeed theoretical results based on those assumptions do not explain collective action behaviour (Poteete *et al.*, 2010).

To provide a full description of all the variables individuated empirically and all the causal chains that have been hypothesized up to now would be a huge task. The number of variables is high as well as the amount of literature that addresses the related causal mechanisms. Differences in research hypothesis and tools often led to different conclusions about causal roles, individuating effects of contradicting sign. Heterogeneity, for instance, has been demonstrated to affect interdependent choices in differing ways depending on assumptions about human behaviour. Strands of literature differ with respect to the weights associated to heterogeneity of framing, of endowments or of goals (Poteete and Ostrom, 2004). Heterogeneity of endowments and homogeneity of goals lead rational individuals to cooperate, while homogeneity of framing is key for cooperation under the assumption of norm driven behaviour (Lynam *et al.*, 2012; Ostrom, 2000a; Stone-Jovicich *et al.*, 2011). It is also remarkable that variables affecting collective action do not belong to mutually exclusive categories: for instance it is hard to explain how social capital affects transaction costs in a group without overlapping issues related to heterogeneity drivers. Ostrom (1990) found several design principles specially affecting the likelihood of a norm to emerge:

- Presence of clear boundary rules within the group .
- Rules within the group are appropriate to the social technological and market context.
- Most of the member affected by the rules can participate in the decision making process.
- Monitors of social norms are legitimated.
- Graduated sanctions existence, sanction ease and access to justice.

- Exit strategies.

Based on a selected literature review (Agrawal and Ostrom, 2001; Beckmann and Padmanabhan, 2009; Gibson *et al.*, 2005; Olson, 1965; Ostrom, 2000a, 2008; Ostrom, 2009; Ostrom, 2010; Poteete and Ostrom, 2004) we present other variables relating to group and resource features that seemed especially appropriate to our purpose, and for which theoretical explanations appear more relevant to the context.

- Group size: it is always significant in empirical analysis, but with ambiguous sign. Cooperation in large groups may become less likely due to increasing transaction costs and free riding problem, however a larger group is more able to leverage external resources.
- Heterogeneity of participant (specifically addressed in Chapter 6), may relates to mental models, endowments or goals. In our case mental models may relates to experienced damages and perceptions of fire risk, endowment refer to the effective capacity to control fire, and goals may differ depending on fire sensitiveness of the planted crops.
- Information about past actions increases the ability of monitoring and sanctioning, increasing the effect of reputation and increasing the survival probability of cooperators.
- How individuals are linked as well as the face-to-face communication opportunities. The tightness of social capital that shape the interaction and the power relations in a community, the level of institutionalization of groups and norms, and the level of organization to reach common goals may reduce transaction costs and increase trust. These issues seem to the author a relevant issue in a context in which actors are spread-out in a large space.
- Monitoring and sanctioning activities are fundamental to reinforce norms and reduce free riding, especially in a context poor of formal institutions as the rural areas in the Brazilian Amazon.
- Leadership in the group increases the probability of innovation. It explains the onset of new norms and provides the fundamental stimulus to undertake collective action.
- A common knowledge of technology reduces conflicts in decision making by reducing transaction costs, but it may create situations of lock in. Technology hold an important role in fire control collective action, coordination

or conflicts may arise depending on beliefs relating to fire use and the effectiveness of fire control techniques.

- The importance of the resource to the user increases commitment to collective action since the expected benefits issue of cooperation increase.
- Size of the total collective benefit and marginal contribution by one person to the collective good, both affect the size of the temptation to free ride.
- Loss of co-operators when the others do not cooperate may increase commitment to punishment, but depending on heterogeneity of goals may undermine the likelihood of collective action.

No matter how collective action is framed, the commitment and sanctioning dilemmas emerge as two useful heuristics (North, 1993; Ostrom, 1990, 1992). The latter relates to the ex post punishment of co-operators toward free riders, while the first relates to the ability of actors to credibly commit to implement a set of actions (Shepsle, 1991). Commitment is equally important to sanctioning in determining collective action success since it contributes to the formation of the agent's expectations. The commitment dilemma is especially relevant when little sanctioning exists and when uncertainty about the collective action outcome is high (Ostrom, 1990).

Commitment and sanctioning lead to at least two levels of social dilemmas: the first relates to the choice of participating or not in cooperation, to conform or deviate from the norm, and sanction or not free riders. The second level social dilemma relates to the change of rules, and the creation of a norm allowing sanctioning free riders, legitimating and giving sufficient incentives to sanctioners. Creating and changing norms and rules is a collective action dilemma since norms and rules are public goods (Ostrom, 2000a). In our case collective action to create a norm for fire control is a second level collective action dilemma.

3.2.2. Compliance, institutions and geographical economics

We wish to take into account in our framework some other variables that are usually not included in studies on collective action, but that are useful to understand the interaction among institutions, policies and collective action likelihood. In particular we refer to motivational and institutional crowding out effects (Cardenas *et al.*, 2000; Frey and Jegen, 2001; Ostrom, 2000b), compliance motivations to the law (Gezelius and Hauck, 2011; Winter and Fried, 2000; Winter and May, 2001), and the concepts of proximities (Torre and Rallet, 2005).

Participation in collective action depends on whether actors believe that a cooperative success may take place but also that it is their role to contribute to the collective action success (Ostrom, 2000a). This is essential for both single actors and institutions involved in the cooperative game. Farmers, for instance may frame risk as something natural and inescapable or as a risk that can be mitigated, and in this case, whether it is a private or governmental task to take action to mitigate risk. Policy intervention may reinforce motivations to cooperate and improve collective action likelihood, but it may also crowd out motivations and institutions oriented to fire control.

‘Institutional crowding-out suggests that well-intentioned but modestly enforced government controls of local environmental quality and natural resource use may perform rather poorly, especially as compared to informal local management.’ (Cardenas *et al.*, 2000).

Frey and Jegen (1999) define the conditions for motivational crowding in and crowding out:

‘External interventions crowd out intrinsic motivation if the individuals affected perceive them to be controlling. In that case, both self-determination and self-esteem suffer, and the individuals react by reducing their intrinsic motivation in the activity controlled. External interventions crowd in intrinsic motivation if the individuals concerned perceive it as supportive. In that case, self-esteem is fostered, and the individuals feel that they are given more freedom to act, which enlarges self-determination’.

This happens because of changes in preferences and in perceptions about the environment, tasks and self. Policies and norms may have important crowding out or crowding in effects on collective action success especially on the second level dilemma for norm creation and sanctioners legitimation. Crowding in and crowding out impact of policies and norms must be taken into account analysing an interdependent choice.

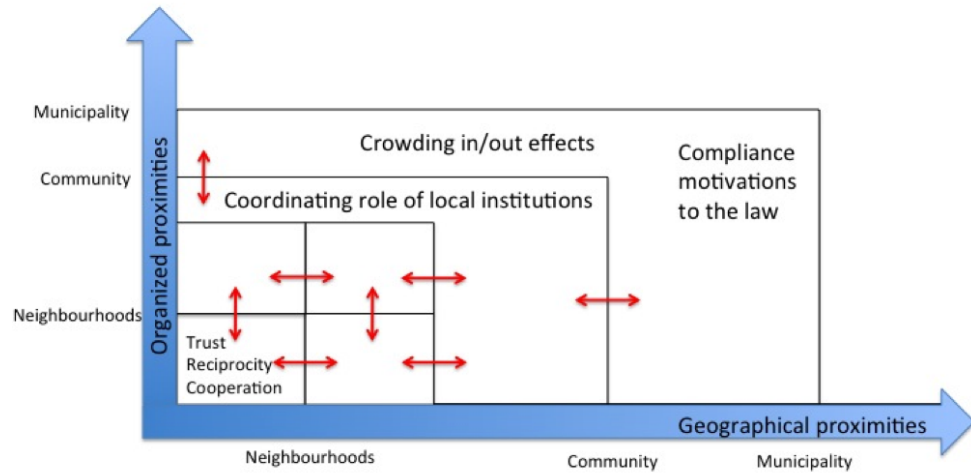
Since fire control is mandatory by law, compliance motivations also enter in fire control choice. Law in this case, even if very poorly enforced may support coordination and crowd in motivations to participate in fire control. Winter and May (2001) show empirically that compliance with environmental regulation does not depends only on the cost of compliance, likelihood of detection and likelihood of fine as in Sutinen and Kuperan (1999). Compliance, instead, depends greatly on perception of compliance as a moral duty, enforcement style, awareness of

rules and effective capacity to comply. Gezelius and Hauck (2011) stress that three distinct mechanisms operate: a deterrence one depending on enforcement intensity; a moral support for law content one, depending on empowerment of citizens, and a legislator's authority one, a function of civic identity. Moreover it is shown that the relative importance of those mechanisms in explaining compliance to the law varies across countries with the embeddedness of state in society, and across sectors.

Collective action and fire hazard may take place at different scales, and the level at which collective action can emerge may not be the most efficient to mitigate fire risk. This potential mismatch can affect the likelihood of collective action. Following Torre and Rallet (2005) we distinguish between organized and geographical proximities. The latter emerge from the reduced distance among actors and have often been confused with organizational proximities. The former are made up by institutions, norms and organizations that allow to cooperate or bargain to overcome tensions and conflicts. Geographical proximities can be sources of conflicts related to consumption of resources, and may not overlap with organizational proximities. In our case geographical proximities are sources of conflicts because fire contagion takes place first of all in the neighborhood of ignition sources. On the other side organizational proximities may operate at an excessively high or excessively low scale. In the first case transaction costs are too high, in the second case coordination costs are too high.

Summarizing, we discussed here all the heuristics we used to collect data and interpret results of interviews. Collective action depends on a key trust-reciprocity-cooperation loop. Several variables related to group and resource features affect this loop; moreover the formation of trust and reciprocity relates to different levels of collective action dilemmas, involving both the dimensions of sanctioning and commitment (Figure 2.1). Institutions may play an important role in explaining cooperation and can be analysed with normative intent to define how they can provide incentives to improve collective action likelihood. For this purpose we introduce the concepts of institutional crowding out, crowding in and compliance motivations, and we distinguish between organized and geographical proximities. Figure 3.1 report geographical proximities on the x-axis and organized proximities on the y-axis. Small rectangles refers to neighborhoods in which collective action for fire control may take place. At the community level local institutions may provide coordination either between neighborhoods either with higher level institutions. At the municipal scale policies affect compliance motivations to the law and may crowd-in or out institutions and motivations for fire control.

Figure 3.1: Theoretical framework



3.3. Goals: methods and data

3.3.1. Methodology

We conducted a two-month field study in the municipalities of Ipixuna do Pará and Paragominas. These two municipalities are located in the so-called "arc of deforestation" in the north-east of Pará.

We carried out 60 semi-structured interviews in 15 heterogeneous communities. The interviews were conducted with key stakeholders, identified thanks to information provided by the community leaders and local organizations. The profile of the key stakeholder is extremely variable, from farmers behaving in a particularly innovative or entrepreneurial way to farmers who have suffered serious injury from fire contagion or who have implemented novel approaches to control fires, to farmers fulfilling an important role in the organization of the community. The number of interviews in each community depended on the degree of complexity met. Interviews were aimed at understanding the collective action dynamics in each relevant group with respect to fire issue. Many times the community was not the right level to study collective action: neighboring relations and informal groups seems to cover an important role (Agrawal, 2001). As remarked in other case studies on collective action, communities and groups have very different features and cannot be grouped under a unique definition (Beckmann and Padmanabhan, 2009; Gibson *et al.*, 2005; Poteete and Ostrom, 2004). The only operational criterion we used to define groups is the organized and/or geographical proximity with respect to the fire issue. Those criteria were

verified with maps, observation and introductory conversation with leaders of communities or of local organizations.

Interviews were also conducted with officers of local and country institutions including the officers of PrevFogo, officers from EMATER and EMBRAPA¹ of Paragominas, the Secretary of Environment and the Secretary of Agriculture of both Paragominas and Ipixuna do Pará. These interviews aimed to understand how government officers perceived the fire issue, and how they implemented related policies.

All relevant data collected in the interviews were then triangulated with data from other key stakeholders within the same group and at least one farmer randomly chosen within each group or community. In some cases, the information was discussed in a meeting with the group.

Information was then organized in a database by community or by group. Appendix A provides the list of questions used in interviews.

3.3.2. The context of the study: Paragominas and Ipixuna do Pará

Our study explores how smallholders' perceptions of fire risk may influence fire use and control. Previous works showed that fire risk and the preventive measures to control it vary according to the type of landscape (open pasture, forest) (Nepstad *et al.*, 1999) or to the type of social norms (traditional communities, recent settlements) (Brondizio and Moran, 2008). We also assume they may vary according to the type of policies that address the fire problem. We consequently selected a variety of communities in two neighboring municipalities, Paragominas and Ipixuna do Pará, both located in the post-frontier region of Pará state (Figure

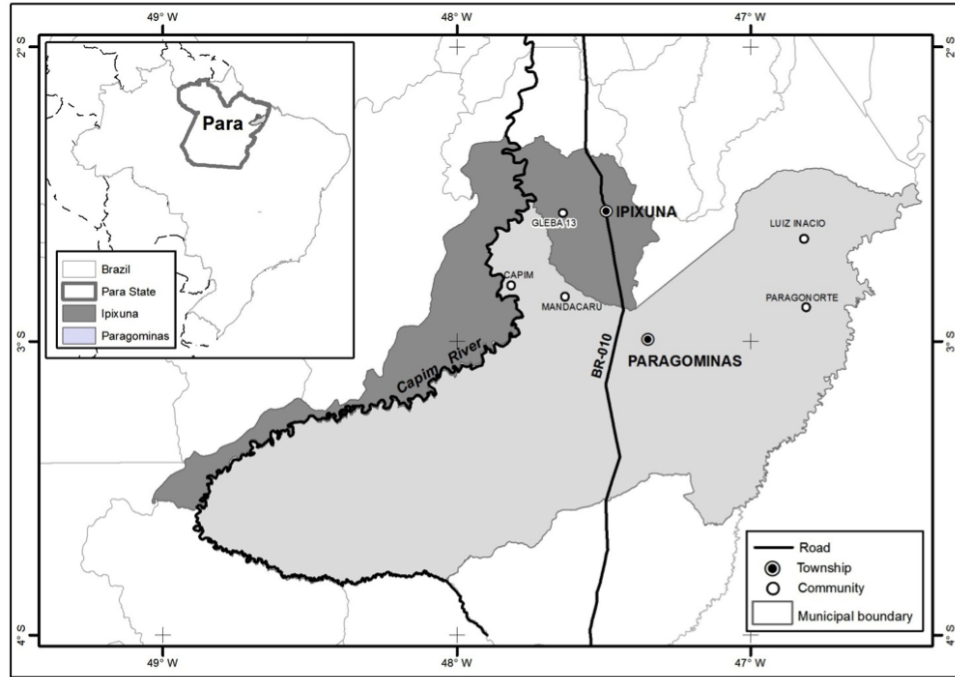
Paragominas

The municipality of Paragominas was chosen as it is usually considered a case of success of sustainable management policy, and holds a wide range of different communities.

The first colonization in the region started in the thirties by *ribeirinhos* farmers (Uhl and Almeida, 1996). Paragominas was settled at the end of the fifties, experiencing three productive cycles up to now. The true colonization started in the fifties opening the region to cattle breeding, strongly incentivized by the government (at that time mainly concerned by cattle export increase to

¹ The organizations respectively charged of technical assistance and research for agriculture.

Figure 3.2: Identification of the communities visited for the study



Source: Cammelli *et al.* (2014)

restore the balance of payments equilibrium). Cattle breeding continued being the main economic activity until logging started to take place on a large scale in the eighties, overtaking cattle breeding. At the end of the nineties Paragominas was responsible for 20% of the wood production of the Pará state. At the beginning of the new century a new intensive soy wave started taking place. In 2010 the municipality was the first soy producer of Pará (Coudel *et al.*, 2012; Gardner *et al.*, 2013).

In 2008 Paragominas was hit by the “Arco de Fogo” (Arc of Fire) operation as it was included in the 36 municipalities black listed by the Ministry of the Environment because of illegal deforestation. Violent demonstrations rose hammering away the federal police and the IBAMA agents that were enforcing illegal sawmills and firms closure. In 2010 Paragominas exited the black list and in the Brazilian media was referred to as the example to be followed for sustainable management in the Amazon. A zero deforestation pact was signed among municipal private and public institutions, and the new *Município Verde* (Green Municipality) management model was adopted (Barreto and Araujo, 2012). The Municipal environmental code (law 765/2011) banned any sort of fire, but for smallholders the stick was not followed by any carrot: in fact they experienced

the destruction of carbon ovens, sequestration of chainsaws and other assets, but they didn't received any incentive to move toward sustainable farming. The last two mayors of the town were big landholders and the main focus of municipal policies has been the development of highly mechanized soy and beef production: *agronegocio*.

The majority of our field research was carried out in three areas of this municipality: the first area (Capim region) is characterized by the most conserved environment and is populated by ancient traditional riverside populations (*ribeirinhos*). The other two are land reform settlements; one dominated by degraded landscape and pastures (Paragonorte), while the other still conserves some forest cover (Luiz Inacio) (Figure ??).

The traditional communities were founded in the early 1950s by *ribeirinhos* and were structured following the establishment of Catholic church units in the region. Livelihoods are mainly based on extractive activities, including "roça" and forest resources. They are relatively small communities, with a population ranging between 10 and 50 families per community.

The land reform settlements we visited were created by the INCRA (National Institute of Colonization and Land Reform) in the late 1990s on large properties (Fazendas) that were abandoned after cattle and timber activities declined. Two of them are amongst the largest land settlements in Latin America, with more than 1000 families, organized in communities that usually comprise more than 200 families. The settlers are mainly from the Pará state although they may come from other parts of the country, and their livelihoods mainly depend on crops and cattle.

Today Paragominas accounts for a surface of 19.309,9 km² and 97.788 inhabitants, and only 21,78% of total population lives in rural area (IBGE 2010). In 2009 family agriculture accounted for 159.600 hectares, i.e. the 8,2% of the land in the municipality (Pinto *et al.*, 2009). The main crops are rice, beans, manioc and corn (Pinto *et al.*, 2009); pastures are widespread as well. Perennial crops are rare, Pinto *et al.* (2009) Toniolo and Uhl (1995) Almeida and Uhl (1995) individuated rubber trees, oranges, cocoa, mango, passion fruit, black pepper, cashew nuts and bananas.

Ipixuna do Pará

Ipixuna is a small municipality of 51.393 inhabitants over a 5.216,948 km² territory (IBGE 2010) born at the border of Paragominas in 1991. Interviews concentrated in the Gleba 13 area (Figure ??). It has been included in the research during the

field study because farmers interviewed at the border of Paragominas praised the municipal policies for smallholders in Ipixuna, also with respect to the fire issue. Ipixuna do Pará can be distinguished from Paragominas because of the prevalence of family agriculture, with 76% of the population living in rural communities and a much lower land concentration (Amaral *et al.*, 2011; Pinto *et al.*, 2009). Ipixuna is not as interesting as Paragominas from an historical point of view, but it developed interesting policies addressing various problems of family agriculture, among which a special program to control fire. Another interesting feature is that Ipixuna didn't enter the Arco de Fogo black list, and seems more compliant with the law (Guimarães *et al.*, 2011), keeping the average annual deforestation rate between 2006 and 2011 under the legal threshold of 40km²/year (Amaral *et al.*, 2011).

3.4. Results

Five main issues have been identified from the analysis of information collected: we first expose the impact of fire contagion on the properties and communities and its impact on production. In the following we discuss the measures of fire control and fire fighting implemented by farmers individually and within groups defined by geographical or organizational proximity (Torre and Rallet, 2005), and their main limitations (difficulty in commitment, monitoring and sanctioning). In a third part we will discuss the factors affecting the adoption of fire control measures, especially reciprocity and market access. Finally, we will assess farmers' perceptions about the role of community and the public action in preventing fires, and the Biennial Programm of Prevention and Combat to Forest Fires of the municipality of Ipixuna do Pará.

3.4.1. Effects of fire contagion and its impact on production

All the people interviewed have suffered damages caused by fire, and no one has been able to point to someone who has remained untouched. However, the intensity of the damages are heterogeneous: while some farmers have not suffered from fires for 6-7 years, some others have suffered damages up to 3 consecutive years.

Some crops require limited use of fire, as perennial crops, but the latter are an investment that takes time to reach maturity and thus are very susceptible to

fire. When asked about why it is so rare to observe perennial crops Seu Zaquinha answers:

‘Suppose I plant fruit trees here, the fire comes and burns everything, what do I do then? What will I be doing here? (indicating the other farms) [...] But if the fire stopped coming, then I would plant açaí, cashew, mango, bacaba, and all I would need! But will I clean an area, plant trees and fertilize them knowing that fire will come and kill everything?’

The major damages caused by accidental fires concern perennial crops, pastures and fences. In case of absence of subsidies for cattle breeding fires push farmers to produce almost exclusively annual crops as a strategy to mitigate fire risk (Figure 3.3).

Figure 3.3: Burnt perennial crops victim of fire contagion from the adjacent plot are substituted with manioc crop



However, it happens that even annual crops are damaged by fires, in which case the family lives from extractivism and day labor:

‘Those losing even their *roça* can sell some days of work, fish, hunt or collect açaí... Nature is benevolent!’ (Seu Adalto)

Despite experiencing huge damages from fire, there is a clear preference for slash and burn, especially among those who have experienced alternative techniques, such as slash and mulch or the use of the tractors. The latter in particular requires high initial investments, especially in fertilizers and herbicides, thus implying a strong market orientation and undertaking a higher economic risk. The high level of entrepreneurship necessary to withstand such economic risk has been observed very rarely. By opposite government subsidies for additional inputs are highly demanded. When a tractor is used, complementary fertilizers or herbicides are very rarely used.

Given the prevalent use of fire, the limited alternatives available and the occurrence of fire accidents, fire control and firefight takes on considerable importance.

3.4.2. Fire control, firefight and its limits

The first level at which collective action emerges is the neighborhood. It is actually in the neighborhood that most daily communications takes place, trust or conflicts arise, help and day work are exchanged and fire control measures are set.

In the neighborhood both explicit and implicit agreements are taken about production, e.g. sharing a pasture, and about the preventive measures to be implemented against fires. Discussions reported in interviews include firebreaks that divide two properties, the notification of the date and time in which the burn will take place, or even the decision to burn together two adjacent areas. The neighborhood is thus the "natural" *milieu* within which these decisions are taken. The geographical proximity, in fact, is a key factor in generating the interdependence at the origin of the fire control dilemma. However, these geographical proximities do not always correspond to the organized proximities in which farmers can mitigate risk. A first barrier to the circulation of information and the formation of trust and reciprocity is the lack of communication due to the physical distance between various properties, or the absenteeism of the owners, who may live several kilometres away, in other communities, or have migrated elsewhere, leaving the properties under management to a member of the family or to a trusted person. In addition, an empty property can be dangerous because less labor force is available to deal with an eventual fire in that area, and the probability of identifying the culprit and ability to control the behaviour of an illegal occupier are reduced.

Besides the lack of a responsible for each plot of land, there are other elements arising from the interaction with complex natural systems disturbing the emergence of risk prone behaviours.

Multiple possible ignition sources and variability of weather conditions disturb the perceptions of risk by producers, who are sometimes unable to explain the occurrence of fires and related incidents, or yet the effectiveness or ineffectiveness of the set of fire control measures implemented. This leads to blaming unlikely cigarette butts, badly extinguished cooking fires, arsonist or children who set fire for fun, instead of taking preventive measures in slash and burn activities and renewal of pastures with fire. In other cases, the climatic conditions and the inattentiveness of other farmers increase the uncertainty around the occurrence and intensity of a fire event, inducing to judge it impossible to be controlled, and to consider fires as a normal occurrence.

Problems related to uncertainty of ignition sources are reduced in areas with extensive moist forest cover, but are high or very high in areas of degraded forest or pastures. Where the forest is still damp and unlikely to be flammable, to build firebreaks takes a few days, the removal of some trees and the creation of half a meter width footpaths free of dry leaves is usually implemented without huge deploy of resources. Moreover, even without building firebreaks it is possible to expect a low probability of propagation or contagion.

By opposite, in areas of degraded forests or pastures the risk of fire is much higher and building barriers to propagation is more expensive. Interviewed farmers often show fear of fire, astonished by the ease of spread of fire in the forest, or by the height and the heat of the flames in the pastures that easily bypass even tracks and roads. The only precautions in these cases relate to pasture fences and houses, where fire is easier to be controlled.

Various farmers complain that despite the effort to control fires locally, there is always the threat of '*fogo de longe*', the fire that comes from afar due to a fail in fire control in another neighborhood, even belonging to the same community. Therefore, even if there is sufficient agreement about fire control in a neighborhood, the benefits derived from reducing risk locally may be annulled by the failure of collective action among producers who live a few miles away, especially in degraded areas. Every 3-5 years, in particularly dry summers aggravated by the El Niño event, many farmers experience fires of great extension that can last up to three months, starting with the season of fires and exhausting only with the onset of the rain season.

The randomness of the fire hazard and the climate *alea* produce a high level of uncertainty about the success of collective action. Increasingly fires are perceived as a natural and uncontrollable phenomenon, therefore reducing incentives to cooperate for fire control.

Together with uncertainty, the problem of enforcement of the rules appears to be the main barrier to the solution of the collective action dilemma: if it is relatively easy to discover the source of a fire and the ignition source, it is difficult to find out who is the culprit of the contagion. Except for the abandoned lots, each property corresponds to an owner. Lot abandonment is increasingly frequent in reason of the distance to the market and the low quality of land, especially in land reform settlements. Since farmers set fires on different days, investigations can easily identify the plot source of contagion. Nevertheless the landowner can always exonerate himself by accusing unknowns to have lit a fire on his property. Moreover, the search for the culprit is discouraged by the difficulty in obtaining compensations: farmers do not have money to pay for the damages they may cause, and this reduces the incentives to start a discussion that would lead to antagonize the neighbor and a part of the community with him. In various communities interviewed farmers expressed fear of making complaints or seeking compensation for fire damages with the terms: ‘afraid to be a shot? (*medo de um tiro*) or ‘look goofy [in front of the community]’ (*ficar tolo*).

‘The neighbor is wrong, but if we go complaining he will get angry with us, and we may fight. So if we are damaged by fire, the best is to remain silent.’ (Seu Valgico)

The inability to sanction and implement credible threats against free riders leads to the commitment dilemma: why spend time in taking preventive measures if there is no guarantee that others will do the same?

We frequently observed prevailing annual crops, few perennial crops and poor infrastructure, associated with lack of investments in fire control. A low level equilibrium, in which adaptation to a high frequency of fire contagion takes place by reducing the value of crops at stake, planting the less fire sensitive crops (essential for subsistence livelihoods and resilience but less valued on the market), and reducing productive investments.

If collective action to set fire control measures may have too high costs, we observed a higher level of cooperation in fire fighting activities.

Although collective action to set preventive fire control measures are seldom related, we observed a higher level of cooperation in fire fighting activities. In order to deal with any problem that requires a collective effort, either to lift a fallen horse, clean the streets of the village or fight a fire, any member of the community can ask for help thanks to the self-insurance institution of ‘*mutirão*’: i.e. a collective initiative for the execution of a non remunerated service. A member of the community asks the group to form the *mutirão* to solve the problem, giving

rise to another cooperation dilemma: let the others bear the risk of fighting wildfires, or participate?

The producers interviewed reported physical and psychological shocks, losses of assets, animals and means of transport used in fire fight. The cost of participation is high, and given the limited tools available the outcome is highly uncertain. Moreover helping to fight a fire in a place has the opportunity cost for farmers of leaving their own property in a helpless situation if fire should arrive there. However a successful fire-fight in neighboring properties may deviate the wildfire and avoid fire contagion of their own property. Fire fighting increases in danger and decreases in effectiveness when areas of degraded forest or grassland are involved, as flames can affect the treetops, ablaze trees may fall and sparks can be spread everywhere by the wind.

Nevertheless, by its impromptu emergency nature, it is easier to achieve cooperation in firefighting than in fire prevention and control. Firefighting usually limits the damages to crops, but cannot avoid the degradation of the surrounding forest. In fact, the goal of firefighting is generally to divert the fire out of properties but not to extinguish it completely.

PrevFogo the specialized branch of IBAMA in prevention of forest fires, offers training and provides some equipped patrols to assist in fighting small fires. However, these patrols are definitely not sufficient to deal with emergencies: too few in numbers they only reach the areas connected by roads. Farmers are often unsatisfied with their work, and tend not to call for help, intimidated by the inspective style used to gather the information necessary for their reports (questionnaires, movies, and a little investigation to find a culprit).

In summary, the main difficulties in achieving collective action around fire control are issued from monitoring and rules enforcement difficulties, and from a great deal of uncertainty with respect to the results, due to the non-coincidence between the geographical proximity in which fire contagion takes place and organizational proximity in which risk mitigation strategies can be implemented. Transaction costs to solve the fire control coordination problem in community institutions is sometimes too high. Community institutions operate at an inefficiently high level and are unable to provide solutions to neighborhood conflicts. Uncertainty and enforcement difficulties make it hard to build trust and reciprocity, leading to a non-acceptance of risk and therefore to a preference for a low level equilibrium, planting low valued crops and setting no or poor fire control measures.

3.4.3. The adoption of measures to control fire: reciprocity and market

Reciprocity is key in building trust and cooperation. Market may provide additional incentives to cooperate, but it may also relax social linkages within the community, reducing reciprocity.

Many market-oriented farmers have a general preference for cattle-breeding, because of prices are relatively stable and cattle involves little risk. However, few farmers have perennials, such as fruit trees or timber. By opposite, in groups or communities with lower access to market, subsistence agriculture dominates. Preferences go for *roça* (annual crops), which constitute the basis of local diet, and an income source from the sales of the surplus. Livelihood oriented producers use to share labor force and production in the neighborhood and the community. In the community of Santa Rosa the first goal of production is livelihood, only exceeding production is sold to the *atravessador* (intermediary) that pass monthly on the river. Most of the production is consumed locally and exchanged as a gift:

‘(...) We consume, we give, here in the colony it is not as in town, where everything is bought. Here in the colony neighbors give me some pounds of flour, something from the *roça* [...]. If somebody is in the need everybody shares either food or labor. ’ (Seu Dequelo).

Interdependence and reciprocity between members of the community make monitoring and sanctioning activities easier and increasing both moral and material costs of free riding due to the risk of loss of relational and non-relational goods.

The visited communities located closer to the cities are younger, with little or no forest cover, and usually allocate half of the land with extensive pastures. On the contrary, communities living in remote areas with poor access to the market are older, occupy the area since several generations, but retain a greater forest cover and are opposed to the introduction of cattle breeding. Within the visited communities, where reciprocity and trust were more intense, forest were still standing, suggesting that fire accidents have been limited and that collective action has had a role.

Greater access to the market, however, allows a lower heterogeneity of objectives among producers in the area, creating greater confidence and certainty with respect to the control of fire. We observed a group of about twenty neighboring producers who look after the cattle of a neighboring *fazenda* in their ranches. They have chosen to stop using fire, and have implemented an effective system of fire fighting: quickly warning and gathering on the side of a little stream from which the

wildfires usually come, and protecting all the properties. Loosing pasture and cattle heads would mean for them to loose all means of production and fall into debt.

‘Fire always come from afar, among neighbors we don’t worry, we’re all in the same situation’ (Dona Elisangela).

Since five years the system is in effect, and they cancelled the incidence of fires on their properties. However market access is not a panacea. It reduces the interdependence between neighbors and thus the possibility of social control. Access to the market also changes the definition of the situation, the mental model used to define the problem, encouraging rational behaviours, but crowding out intrinsic motivations to control fire. In two communities near the city we observed a sort of Coasean bargain solution, where a neighbor planting perennial crops, therefore more interested in fire control, paid a worker to build of a firebreak around the *roça* of the neighboring property that only had annual crops and was less interested in fire control.

In other cases intrinsic motivation to control fire were totally crowded out by expectation linked to possible payment for environmental services by the government (although no concrete project exists locally), using as argument the fact that the forest is a public good:

‘If the government wants the forest to stand, the government must pay².’ (Seu Adaltinho)

Some other requests toward the government related to public financing or provision for caterpillars to build firebreaks, or tractors, fertilizers, herbicides and seeds, as a condition to make an efficient transition out of slash and burn.

This change toward a market orientation can lead to greater investments in fire control, under the conditions that the capacity to bargain among producers to get better solutions exists and that the government is willing to pay for environmental services or to subsidize a transition to mechanization or toward alternative techniques to the fire. However, in the absence of such conditions the risk of a reduction in investments in fire control as a result of reduced intrinsic motivation and dependence from external subsidies may increase. From the preference for standing forest, to the preference for standing payments or subsidies.

² Here the interviewed refers to the pilot program Bolsa Verde of the Brazilian government, a type of payment for environmental services made in collective management plans to encourage farmers to respect the rules and limit their *roça* to 2 ha (but this does not apply in the communities we visited).

3.4.4. What role for the community?

We often observed insufficient individual incentives to sanction those who do not control fire. This appear to be the effect of difficulties in identifying the culprit, the fear of retaliation in terms of relational goods, direct social sanctions or just the fear of "appear goofy" and environmental uncertainty. The general acceptance of a low-level equilibrium leads not only to fires and poverty, but also to a further serious problem of latent conflicts and missing sanctioning, because people stop completely claiming compensation or reporting accidents. Lack of sanctioning takes place on the one hand because under conditions of widespread poverty it is reasonable to expect that the neighbor is not rich enough to pay compensation, on the other because investing in fire control measures has become inconvenient, for everyone. A rule of silence becomes an institution: in which nobody reports anyone so as not in turn be reported in the future. On the other side, to produce a rule for fire control is a public good that assumes unacceptable costs for the individual farmer, and an external intervention is needed to accompany the work of local leaders. In the words of the president of a local farmer association:

‘We need somebody, somebody powerful and influential that comes here and speaks to everybody’. (Seu Cearense)

The communities visited always had some levels of organization and centralized governance. We individuated local associations and the Catholic Church as the most influential with respect to the fire issue.

Each community is headed by one or more recognized associations, often created by necessity to interact with the Institute of Agrarian Reform (INCRA), the intermediary for access to land and credit. However, these associations, are almost entirely devoted to lobbying the INCRA and the local government, and show little concern about the internal organization of the community. This brings to sort of institutional crowding out, in which the energies offered by an elected leader are entirely devoted in legitimately asking external aid (i.e. in terms of infrastructures, technical assistance or credit), but disregarding issues related to internal organization and coordination. The chronic delays of INCRA, a true bureaucratic legend that has not undergone reforms since its founding in 1970, have discredited the associations and their presidents within their community. In all the associations there was a fall in the number of associates and a drastic reduction in the frequency of meetings: from twice a week, to trimestral, to almost yearly. Community leaders role have been downgraded to that of secretary for external governmental institutions, responsible for all failures, devoid of charisma

and with no role in community organization. In the words of the president of an association:

‘My job is to ask for outside help’. (Dona Maria)

Some presidents of association denounced a lack of authority that has been created over time, in which even the most charismatic people no longer have the right to be heard. The total dependence on public subsidies in the form of transfers, subsidized credit and technical assistance, make farmers perceive more and more a dependence toward the government and increasingly less responsibility towards the environment that surrounds them, by the requests for payments for environmental services or the demand for fertilizer, herbicide and tractors for free.

In more traditional communities, the Catholic Church has a central role in local organization. Stands the figure of the *coordenador* (an elected farmer charged as deputy priest) and of the also elected *coordenadora*, with no or few links with external organizations, and with the sole task of organizing community life. The *coordenadores* have proved more effective than the presidents of the association in raising awareness about the issues of fire, coming to punish free riders, even with ad hoc meetings. Nevertheless, the effectiveness of their intervention is highly variable and depends on their leadership skills.

Of course the priority of every member of a community is primarily to preserve good relations with his neighbors to not loose the benefits of reciprocity. Applying penalties may create a conflict; unless a free rider brought massive damages to many farmers, there will be insufficient agreement to sanction an individual. Seu Raimundo Nenè, who reported a neighbor, explains that the reason is straightforward:

‘Denouncing is not worth it: I have lost my serenity. Now, when I hear some noises in the night, even if I imagine it is just a chicken thief in my backyard, I stay in my bed.’

Another issue concerns the heterogeneity between neighborhoods. The interest of starting a sanctioning activity in a neighborhood depends on the expected benefits of a successful collective action. If benefits are uncertain because of the fires coming from the surrounding neighborhoods, there will be few incentives to produce rules and to enforce them. Successful collective action in one neighborhood is threatened by failure in another one. Church and associations can play a role of coordination between neighborhoods, increasing trust and social capital. However in many communities the lack of results from lobbying the INCRA has caused divisions within the associations and a multiplication in their number. The same happened

with the religious communities that multiplied with the arrival of Evangelical Churches, Adventist, Jehovah's Witnesses, etc. Many farmers reported that the religious functions and meetings of the associations were frequently an opportunity to discuss topics related to fire use and control in formal or informal ways. People who would never risk antagonizing a neighbor asked the president of the association or *coordenador* to speak publicly against *free riders* as a form of sanction. Other strengthened by the group spoke in the first person. Seu Francisco, states:

‘Things have improved. . . People talk in meetings, some people have even asked me not to call their names! I think they are more careful.’

The aggregative function carried out by the association and the church is particularly important in those communities where there is no village, where there is no clear meeting place and farmers built their houses on their plots of land. The absence of meetings involving all members, and the proliferation of sources of authority, churches and presidents, further increased the between neighborhood uncertainty since inter-vicinal meetings occur more rarely, and there is lack of opportunities to discuss rules and implement social sanctions.

About formal sanctions and access to justice some farmers legitimately argued that it is not their task to go to neighbors asking for compensation or impose penalties for accidents, it is rather a government task to impose the rule of law. With this respect some farsighted presidents called for a return of the authorities: some exemplary sanctions to be applied, so that their work as coordinators and sanctioners will be legitimated once more.

‘Everyone knows how to do it [to control fire], but what is lacking is a punishment. What lacks is understanding, consciousness, meeting with powerful people.’ (Seu Baiano)

Enforcement of the law by the government in rural Amazon is challenging because distances are big, and poor infrastructures makes it difficult for policemen to go to all areas, especially in the rainy season. Only in one community over 15 we observed a stable police patrol (for about 6.000 farmers of all the Land Reform settlement). It was settled there only after serious problems linked to drug and stolen cars trade and child prostitution.

In summary, the task of monitoring and sanctioning in the community is extremely burdensome because of the lack of legitimacy of sanctioners. The organizational capacity of the community has long been undermined by dependence on external institutions. The community leaders have lost their legitimacy, and the most long-sighted among them claim an external intervention that restores

authority and predictability with penalties and fines, restoring a role for community organization. The degradation of the social capital due to the de-legitimization and multiplication of institutions and the sources of local authorities has further reduced the opportunity of building trust and reciprocity in the community, increasing uncertainty about fire contagion and reducing the incentives to apply sanctions in each neighborhood.

3.4.5. The Biennial Programme of Prevention and Combat to Forest Fires of the municipality of Ipixuna do Pará

The municipality of Paragominas has not implemented any policy to prevent fires since 2011 when any use of fire has been prohibited (Law 765/2011). This prohibition has remained only on paper. Public action described so far concerns almost only federal agencies such as PrevFogo, the specialized branch of IBAMA, the technical assistance of EMATER and EMBRAPA and the administration of INCRA on federal lands. Resources made available from the Secretary of Agriculture for smallholders are insufficient and goes in the direction of alternatives to fire, disregarding present problems related to fire control.

In the municipality of Ipixuna we observed a diametrically different policy orientation, specifically oriented towards fire control and fire fight rather than to fire alternatives, entirely conceived by the Secretary of Environment of the municipality: the Biennial Programme of Prevention and Combat to Forest Fires of the municipality of Ipixuna do Pará, carried out between 2011 and 2013.

Flagship actions included:

- A new administrative *iter* to obtain the fire use license, enabling to obtain the license at the local environmental secretary instead of going to Belem, the capital of the state which is 250 km away. Lowering travel costs highly reduced the cost of compliance with the law.
- Improvement in coordination between the various municipal institutions interested in fire control. This allowed increasing the frequency of controls.
- Fire fight and fire control training has been carried on in several communities.
- Style of the inspectors was mainly oriented to provide appropriate skills and offering themselves as referees to resolve conflicts between neighbors. Monetary sanctions in conformance to the law were applied only twice in two years, one to a smallholder and another one to a latifundist.

Although the law provides harsh penalties for environmental crimes caused by fire, reconciliation among farmers causing fires and farmers damaged by fires was set as a priority. This eliminated much distrust, increased perception of fire contagion as a crime needing compensation and led farmers to perceive the inspectors as partners.

‘In fighting fire the role of the community and that of the government it’s just one, I make no distinctions.’ (Seu Cidalino)

All respondents in the municipality of Ipixuna were aware of the need to apply for a license for fire use, and that two monetary fines had been applied. Talking about fires and fire contagion was no longer a taboo; several cases of monitoring and social sanctions applied within the community were reported in interviews. Seu Felisardo states:

‘Since two years there have been no more accidents, now everybody requires a license [...]. Three others and myself went to control [the neighboring properties], and we found that he [the neighbor] had not made a meter of firebreak! We spied him to check if he was able to control fire anyhow [...]. Before the law [the license] nobody was building firebreaks!!’

The law mentioned by the farmers is the licensing system, before which there was no knowledge about the legal obligation to control fire.

According to the Secretary of the Environment the initial goal to reduce urban air pollution from smoke during the fire season was achieved, reducing fires. Moreover interviews show that this program also proved to be extremely effective in reducing fire risk perception and perceived legitimacy of sanctioners among farmers. None of the respondents in the municipality of Ipixuna recalls fire incidents during the two years of the program, and the project manager reports that more than 200 licenses have been granted each year. A reduced risk perception, an increased effectiveness of the licensing system and little memory of fires during the period of the programme indicate a higher compliance level to the law in Ipixuna than in Paragominas.

The attractiveness of this policy lies not only in its effectiveness, but also in its reduced costs: about 22.000 over two years. Other policies such as the promotion of mechanization or intensive techniques are in fact much more expensive, and raise doubts about their appropriateness and ecological impact.

3.5. Discussion: the emergence of rules that facilitate cooperation

3.5.1. The role of institutions

The main problem in achieving a collective action success in the fire control dilemma comes from the difficulty in monitoring and enforcing rules and from the great deal of uncertainty of collective action outcome. The non-coincidence between the geographical proximity in which fire contagion takes place and the organized proximities in which it is possible to agree on rules for fire control had a magnifying effect on the challenge of monitoring and enforcing rules. On the one hand higher level organized proximities are not sufficiently “thick” to counteract local conflict, for instance: farmers can agree on fire control within an association, but without all the members of a neighborhood being part of the association. On the other hand organized proximities may operate at an inefficient scale to guarantee coordination: farmers may undertake collective action in a neighborhood, but for fire control to be effective it is necessary that agreement spread among neighborhoods. Monitoring and geographical proximities mismatch makes it difficult to build trust and reciprocity, leading to a non-acceptance of risk and therefore to the preference for a low level equilibrium, with less investments in fire control and few fire sensitive crops. Even if a higher financial return can be expected from fire sensitive crops, i.e. fruit and tree plantation (Almeida and Uhl, 1995; Browder *et al.*, 2005; Hoch *et al.*, 2012; Vosti *et al.*), Pokorny *et al.* (2012) show that fire has threatened crops in two thirds of 50 case studies of tree plantations they reviewed.

The link between fire control and market access, though exalted in the literature, remains ambiguous. On the one hand, old and isolated communities with high levels of reciprocity retain a greater area of forest cover. On the other market provides access to more resources and incentives to invest in fire control and can create homogeneity of goals; but it can also cause motivational crowding out. Increasing market orientation may paradoxically increase dependence on public subsidies in the form of increased demand for subsidized mechanization, subsidized credit, roads and infrastructure, and reducing the bonds of interdependence in the community and degrading social capital (Pokorny *et al.*, 2012).

3.5.2. The role of situational framing

Landscape flammability is key in determining costs and benefits of fire control either in virgin as in excessively degraded areas. In the first because the benefits of collective action to control fire are too low, as the forest is moist and fires are unlikely; in the second because the costs of controlling fire are too high and it could be hard to find sufficient agreement among farmers.

The climatic *alea* is also acknowledged as a determinant of forest flammability, and thus the need for fire control. Farmers are scared of large fires and are sometimes convinced that there is no conceivable role for their agency in controlling fires. The larger variability of weather events and the related effects on fire control effectiveness produce a kind of noise in farmers' perceptions (Brondizio and Moran, 2008). As a result local perspectives confounds about the effectiveness of fire control measures. A poor perception of risk factors leads to non-acceptance of the risk and to the non-adoption of fire prone behaviours (Pégard, 2010).

Results exalt the role of situational framing as a crucial element in the fire control choice. If fire damages are considered taboo, producing a rule for fire control and monitoring and enforcing the rule is almost impossible. Carmenta *et al.* (2013) found that nobody of the 163 interviews ever demanded compensation for damages and asking if there was any procedure to set compensations she got the answer: 'No, we don't have this here. It burnt? Then it burnt'. Indicating that no mechanism to recuperate damages due to fire escape exists. This fact has been widely observed in most of the communities visited in Paragominas. On the other side all the interviewed farmers from the municipality of Ipixuna reported different feelings. Controls carried out by the Secretary of Environment have increased confidence in cooperative behaviour between neighborhoods, reducing the uncertainty caused by fires 'that come from far away'. This has increased the expected benefits of collective action in the neighborhood, increasing incentives to control fire and to monitor and sanction free riding neighbors. The existence of clear and well-known laws and the implementation of the licensing system have legitimized the action of sanctioners, reducing free-riding.

Fire was no more a taboo, but a debatable issue.

This corresponds to a change in actor framing. According to the theory of compliance, the effectiveness of coercive policies depends on the fear of the controls and of the sanctions (Sutinen and Kuperan, 1999). It may seem surprising how the limited resources available to the Ipixuna fire prevention program, and the limited threat of fines (only two monetary fines applied over two years) on a territory as vast as those of a municipality in the Amazon, have been sufficient to achieve

a similar result. Changing actor framing in the direction of collective action may explain the high compliance level and the change in perceptions reported in interviews.

In Paragominas the government has betrayed expectations, and social capital degraded. Solving the commitment problem it is harder since controlling fire has become inconvenient: it is not possible to form reasonable expectations about an internal collective action solution. Some farmers preferred attempting to find exit strategies that are often relatively expensive and little affordable for most of them. Exit strategies include migration to virgin areas or with smaller fire risk, or hire heavy tractors to build firebreaks around the whole property.

In Ipixuna farmers perceive governmental agents as a partner not as controller, the fire control program was perceived as *supportive* and not *controlling* of farmer practices, though it is fair to suppose that a *crowding* in effect operated, increasing incentives to set fire control measures.

The program not only had a direct effect of deterrence, but has benefited from an indirect multiplier effect, by reducing incentives for free riding, reducing the cost of sanctions, increasing trust between neighborhoods, and increasing the benefits of collective action in favor of the control of fire.

In the end, poor coordination between neighborhoods, difficulties in setting and enforcing rules, an unfavorable situational framing, and the difficulty to update rules as a function of the changing surrounding environment explain why social capital (Simmons *et al.*, 2004) and commitment to the community (Carmenta *et al.*, 2013) have not led to increased investments in fire control. The apparent unity of a community may conceal enormous latent conflicts due to damages caused by the spread of fire between neighbors.

3.5.3. Improving the policy space

Public intervention up to now has individualized the problem of fire control insisting on technical aspects (Coudel *et al.*, 2013, Sorrensen, 2009). It accelerated the degradation of the quality of community institutions, reducing the intrinsic motivation to control fire through welfare policies and shifting collective action effort from fire control to the leverage of external resources.

Public intervention ought to strive towards facilitating cooperation for the adoption of fire control measures, and not just providing individual skills, because farmers may have no incentives to adopt them.

The activity of PrevFogo has always been prone to provide trainings and patrols helping in fire fight. However, the effects of these actions are modest

because the adoption of the suggested practices can be inefficient either in virgin or in excessively degraded areas.

PrevFogo prioritizes intervention on two criteria: the frequency of fires in the past and an ex-ante prioritization of areas: Protected Areas first, such as Indigenous Reserves, and Land Reform Settlements follow.

Focusing prevention interventions in the communities where collective action is still a sustainable option would be an effective criterion to reduce fire contagion. Collective action depends on a large array of factors, and among them on landscape features. Thus public intervention should prioritize areas where costs of collective action are still affordable (thus not excessively degraded areas), or where benefits of collective action are sufficiently high (not areas with perfect forest cover). As Brondizio and Moran (2008) suggest, improving information about climatic conditions may reinforce incentives to invest in fire control measures when benefits are higher, i.e. when long summers and drought are expected.

With respect to communities in degraded areas, it is unlikely that they will achieve sufficient agreement for a successful collective action solution because the costs of controlling fire are too high with respect to the effectiveness of fire control measures. A transition out of slash and burn through the adoption of farming techniques with low or no use of fire (as slash and mulch, vegetables or perennial crops, or by subsidizing the adoption of mechanization and fertilizers) could be part of the solution. Improving market and credit access and providing appropriate technical assistance can be a good tool for aligning the expectations of policy makers and the motivations of farmers. However, perennial crops and market access have failed to provide sufficient incentives to abandon fire, while local solutions are less prone to suffer ownership problems (Hoch *et al.*, 2012; Pokorny *et al.*, 2012). In particular, market-based solutions require widespread entrepreneurship and willingness to undertake economic risks, those conditions have been rarely observed in the 15 communities visited.

Empty properties threaten cooperation on fire control, increasing uncertainty of the collective action outcome and reducing the expected benefits. It would therefore be appropriate to have more control on the residence of the owners. This action is usually delegated to local associations. Restoring farmer's confidence in associations is necessary for associations to achieve their goals. The importance of a centralized coordination or hierarchy in solving problems of collective action is evident in the literature (Lichbach, 1996). In this regard it would be expedient to reform INCRA in order to increase the speed of response to the demands of communities and reduce farmers dependence on outside institutions, allowing the

revitalization of associations and social capital in communities.

Where fire control is not implemented due to the commitment trap, as it has been largely observed, public action should be aimed at restoring confidence in the communities and reducing the cost of sanctioning to solve the second level collective action dilemma. Local policies can be effective in achieving this goal. This has been well demonstrated in the case of the Biennial Programme of Prevention and Combat to Forest Fires implemented in the municipality of Ipixuna do Pará.

3.6. Conclusion

Forest fires do not appear to decrease hand in hand with deforestation (Aragao and Shimabukuro, 2010), and threaten the savanization of the Amazon rainforest (Nepstad *et al.*, 1999). Current policies have so far proved ineffective in stopping this trend. There is a lack of field studies aimed at understanding phenomena that lead to fires (Carmenta *et al.*, 2011). The common hypothesis of exogenous fire risk in the studies carried out so far has limited current research and led to individualize the problem of underinvestment in fire control measures.

Assuming that the risk of fire spread is exogenous with respect to the individual, but endogenous in the neighborhood, there emerges a collective action dilemma that often leads to a low-level equilibrium with poor control of fire and little productive investments. In order to find a solution to the collective action dilemma it is necessary to understand the process of actor choice and create policies that align farmers motivation and policy makers goals.

We described the main reasons driving the choice to control fire or not and the emergence of collective action. In particular discussed the role of the main formal and informal institutions involved in fire prevention: neighborhood, mutirão, church, local association and the municipal government. We identified multiple scales at which collective action may take place and the mismatch of geographical and organized proximities, the implication of adverse situational framing for collective action likelihood and the factors affecting compliance to the fire control law.

In the following Chapter we take stock of current knowledge to sketch a simple formal model representing the main features of the fire control choice.

Chapter 4

The determinants of fire control choice

4.1. Introduction

In this Chapter, taking stock of knowledge acquired during the field work (Chapter 3), from literature review (Chapter 1) and of methodological issues (Chapter 2), we model farmer choice to set fire control measures. As emphasized by Morello (2013), the choice of investing in fire prevention measures is close to that of choosing the optimal investment in wildfire protection through defensible space studied by Shafran (2008). Here we discuss Shafran's argument in the context of fire control, showing that multiple equilibria may exist, and that farmers may get stuck at low-level equilibria if there is insufficient agreement/coordination to set fire control measures. We also show that when farmers are stuck in a high risk equilibria they may cope with risk substituting fire sensitive investments with non fire sensitive investments. Thus high fire risk may impede a transition out of fire use.

In the following we sketch a model to determine the optimal investment in fire control measures based on the previous work of Bowman *et al.* (2008). The rationale of such a model is that risk decreases because of increasing likelihood of collective action (increasing trust and social capital), marginal benefit of allocating labor to fire control measures increases, but the opportunity cost of not allocating labor to productive investment, increases as well. In the third and forth section we will test econometrically the determinants of investment in five fire control measures, showing that trust and social capital are important and significant predictors with positive sign.

4.2. Theoretical models

4.2.1. The definition of risk

Households face both internal and external risk. Internal risk is the risk of fire originating in the own property $\gamma(L_P), \gamma'(L_P) < 0$. It is totally endogenous and depends negatively on the amount of labor allocated to fire prevention L_P . External risk originates from fire contagion among properties. This has two components:

- an exogenous component, ψ , including all factors that farmers can't change, at least in the short term, as landscape type, meteorological conditions and extreme weather events such as *El niño*.

- an endogenous component $\rho(\phi), \rho'(\phi) < 0$, where $\phi(\mathbf{Z}L_P)$ is the likelihood of collective action, i.e. the likelihood that a norm for fire control emerge in the neighborhood. Collective action likelihood increases as the household is more likely to reciprocate allocating more labor to fire prevention, and as \mathbf{Z} , a vector of other factors affecting collective action increases. \mathbf{Z} is considered as exogenous to the i^{th} farmer: it includes essentially social capital and trust and depends also on neighbors' effort to mitigate their own internal risk: $\mathbf{Z} = \mathbf{Z}[\gamma_j(L_{P,j})] \quad \forall j \neq i$.

Thus p , the risk of fire event on a given property, is an increasing function of ψ, ρ and γ .

4.2.2. The strategic dimension of risk management

In order to model the strategic interaction in deciding how much labor allocate to fire control measures we reformulate Shafran's (2008) argument about strategic interaction in setting defensible space around houses to mitigate fire risk at the wild-urban interface. Suppose fire risk depends on the amount of labor allocated to fire control measures by the farmer, on collective action likelihood and on the exogenous risk faced by each farmer.

$$p = p(L_{P,i}, \phi, \psi_i). \quad (4.1)$$

For sake of simplicity we substitute the likelihood of collective action, i.e. the likelihood of a shared norm for fire control to emerge, with collective action outcome: the sum of labor allocated to fire prevention measures by neighbors: $L_{P,i} = \sum_{(j \neq i)} \gamma_j(L_{P,j})$.

Thus:

$$p = p(L_{P,i}, L_{P,-i}, \psi_i) \quad (4.2)$$

with p increasing in ψ and decreasing in $L_{P,i}, L_{P,-i}$, and we assume diminishing return on labor allocated to fire prevention measures. The farmer maximizes his utility corresponding to the expected consumption: i.e. income minus the cost of fire prevention minus losses due to a fire event occurrence.

$$U_i = Y_i(L_{a,i}) - p(L_{P,i}, L_{P,-i}, \psi_i)\delta \quad (4.3)$$

where δ stand for losses. Income Y_i is a positive marginally decreasing function of time allocated to production $L_{a,i}$, where the time constraint is $L = L_{a,i} + L_{P,i}$. The first order condition to maximize individual utility is

$$Y_1 = p_1(L_{P,i}, L_{P,-i}, \psi_i)\delta \quad (4.4)$$

where the subscript 1 denotes the first order derivative with reference to $L_{P,i}$. Relation 4.4 means there is equilibrium when the marginal cost of missed income (Y_i) is equal to the marginal benefit from avoided losses due to risk mitigation ($p_i\delta$). The first order condition to maximize the sum of individual utilities is

$$Y_1 = p_1(L_{P,i}, L_{P,-i}, \psi_i)\delta + \sum_{(j \neq i)} p_2(L_{P,i}, L_{P,-i}, \psi_i)\delta \quad (4.5)$$

where p_2 is the first derivative with reference to $L_{P,i}$ of the probability of fire on other's property as a result of i^{th} farmer's effort in controlling fire, which is positive. Since the right hand terms are negative in both equation 4.4 and 4.5, we conclude that the amount of $L_{P,i}$ that satisfy equation 4.4 is lower than the one satisfying equation 4.5. Thus the amount of $L_{P,i}$ chosen by a farmer that maximize his utility is inefficiently low. Inefficiency arises because a risk externality occur discouraging investments in fire control measures.

Totally differentiating equation 4.4 we obtain the elasticity of farmer's labor devoted to fire control to the amount of labor devoted by neighbors to the same task:

$$\frac{dL_{P,i}}{dL_{P,-i}} = \frac{p_{12}(L_{P,i}, L_{P,-i}, \psi_i)}{Y_{11} - p_{11}(L_{P,i}, L_{P,-i}, \psi_i)} \quad (4.6)$$

Assume the numerator is negative (i.e. the impact of an increase of neighbors labor decrease the fire risk on i^{th} farmer plot, increasing incentives to invest in fire control). Since we assume diminishing return on $L_{a,i}$, the denominator is negative until $Y_{11} > p_{11}(L_{P,i}, L_{P,-i}, \psi_i)$. If denominator is positive (i.e. the benefits of allocating labor to fire control are lower than benefits of allocating it to income production) investments in fire control by the i^{th} farmers and the neighbors are strategic substitutes. If denominator is negative (i.e. the benefits of allocating labor to fire control are higher than benefits of allocating it to income production) then strategic complementarities arise. This is a supermodular game and multiple Nash equilibria may arise (Topkis, 1979; Vives, 1990) and can be Pareto ranked (Milgrom and Roberts, 1990). Equilibria with high amount of labor allocated to fire control are preferred, since increase utility in 4.3, but it can also be that farmers get trapped in a low level equilibria when everybody invests less in fire control measures. As shown in Chapter 3 several mechanisms may lead to select a low level equilibrium.

4.2.3. Fire risk as a cause of lock in effect

It can be that when farmers face high risk and has low incentives to invest in fire control measures they cope with risk by self insuring, substituting higher value fire sensitive crops (B) with lower value non fire sensitive crops (A).

Suppose that the farmer, aware of neighbor behavior, has already chosen the optimal amount of L_P and, given ϕ and ψ , takes fire risk p^* as given. If he chooses to plant fire sensitive crop he would get:

$$E(U) = U_B = (1 - p^*)Q_B P_B - K_B \quad (4.7)$$

where Q_B is the output quantity, P_B is the output price and K_B is the cost of production. If he plants non fire sensitive crops he would get instead:

$$E(U) = U_A = Q_A P_A - K_A . \quad (4.8)$$

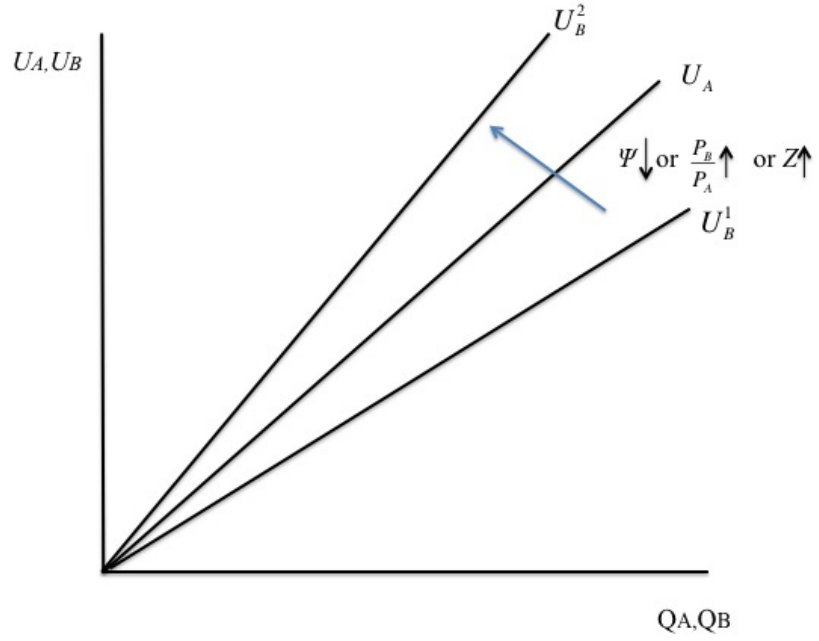
Given the predetermined level of risk he will plant fire sensitive crops only if for any quantity of A and B , $U_B > U_A$ holds:

$$\frac{Q_B P_B}{Q_A P_A} - \frac{K_B}{K_A} > \frac{1}{(1 - p^*)} . \quad (4.9)$$

In order to satisfy condition 4.9 and facilitate a transition, market should provide a large enough price premium for B crop or p^* must decrease. This may happen

because of a fall in exogenous risk ψ , or to an exogenous increase in Z and hence an increase of collective action and a fall in neighborhood risk ρ . Figure 4.1 represent equations 4.7 and 4.8 in a situation of low price premium and/or high risk (U_B^1), and in a situation of low risk and/or high price premium (U_B^2).

Figure 4.1: Effect of a fall in exogenous risk or of a collective action surge on the utility of planting A or B crops.



4.2.4. The optimal investment in fire control measures

Building on Bowman *et al.* (2008) and relaxing their assumptions that only an agricultural good exists and fire risk is entirely exogenous, we aim finding the conditions for optimal labor investments in fire control measures. Farmer sets fire control measures before he face fire risk with probability p of contagion or internal accident, and $(1 - p)$ probability of no fire event.

Therefore, households expected utility is

$$E(U) = pU^F + (1 - p)U^0 \quad (4.10)$$

where U^j ($j = F$ for fire and $j = 0$ in absence of fire) is a standard concave utility function increasing in both consumed goods and leisure:

$$U^j = [\mathbf{X}, N^j, Q_{c,A}, Q_{c,B}^j, l, \boldsymbol{\Omega}] \quad \forall j = F, 0. \quad (4.11)$$

where $Q_{c,A}^j$ and $Q_{c,B}^j$ are the consumption level of agricultural goods A and B . B is not fire sensitive, while A is fire sensitive, \mathbf{X} is a vector of all non agricultural goods, N^j is the amount consumed of non timber forest products (NTFP's), l indicates leisure and $\boldsymbol{\Omega}$ is a vector of household features.

The household can allocate labor L and land S to the production of NTFP's (L_N, S_F), non fire sensitive crops (L_A, S_A) and fire sensitive crops (L_B, S_B). The household can also decide to allocate labor to fire prevention measures,¹ L_p , gaining a positive and marginally decreasing protective effect on NTFP's and fire sensitive crops $\alpha(L_p)$, and mitigating risk p (see equation 4.1).

Consumption functions for NTFP's and production functions for agricultural goods are:

$$N^0 \equiv N(L_N, S_F; \boldsymbol{\Omega}) \quad (4.12)$$

$$N^F \equiv \alpha(L_p)N(L_N, S_F; \boldsymbol{\Omega}) \quad (4.13)$$

$$Q_{p,A} \equiv Q_{p,A}[S_A, K, L_A, L_{h,A}; \boldsymbol{\Omega}] \quad (4.14)$$

$$Q_{p,B}^0 \equiv Q_{p,B}[S_B, K, L_B, L_{h,B}; \boldsymbol{\Omega}] \quad (4.15)$$

$$Q_{p,B}^F \equiv \alpha(L_p)Q_{p,B}[S_B, K, L_B, L_{h,B}; \boldsymbol{\Omega}] \quad (4.16)$$

where $L_{h,B}$, $L_{h,A}$ is hired labor and K is capital. Household maximize utility subject to a cash budget constraint:

$$P_A[Q_{p,A}(\cdot) - Q_{c,A}] + P_B\{p(\cdot)[Q_{p,B}^F(\cdot) - Q_{c,B}^F] + [1 - p(\cdot)][Q_{p,B}^0 - Q_{c,B}^0]\} + I = W_h L_h + \mathbf{P}'_{\mathbf{x}} \mathbf{X} \quad (4.17)$$

a land constraint

$$S = S_F + S_A + S_B \quad (4.18)$$

¹ Fire control measures are labor intensive activities. Since smallholders has little access to mechanized tools to build firebreaks this is a labor intensive activity (Bowman *et al.*, 2008; Nepstad *et al.*, 1999). Moreover as Carmenta (2013) reports, implementing others fire control measures such as burning against the wind, waiting for the first rain, or in the late hours of the day may not result in "good burnt" and may require further work to clear land, chop logs or pull out weeds. This applies to slash and burn for *roça* as in fires for pasture renewal.

and a time constraint

$$T = L_A + L_B + L_N + L_P + l \quad (4.19)$$

where I is the exogenous income and W_h , and \mathbf{P}_x are wage rate of hired labor and the vector of prices of non agricultural goods, respectively. Substituting 4.18 and 4.19 in 4.14, 4.15 and 4.16; 4.14, 4.15 and 4.16 into 4.17 and 4.12; 4.13 in 4.11 and 4.11 in 4.10 and taking P_A as numeraire, thus $P = \frac{P_B}{P_A}$ we can write the following Lagrangean:

$$\begin{aligned} \text{Max}_{L_P} \zeta = & p \{ \psi, \rho[\phi(\mathbf{Z}L_P)], \gamma(L_P) \} U^F[\mathbf{X}, \alpha(L_P)N(S_F, L_N; \boldsymbol{\Omega}), Q_{c,A}, Q_{c,B}^F, l; \boldsymbol{\Omega}] \\ & + (1-p) \{ \psi, \rho[\phi(\mathbf{Z}L_P)], \gamma(L_P) \} U^0[\mathbf{X}, N(S_F, L_N; \boldsymbol{\Omega}), Q_{c,A}, Q_{c,B}^0, l; \boldsymbol{\Omega}] \\ & + \lambda \left\{ [Q_{p,A}(S_A, K, L_A, L_{h,A}; \boldsymbol{\Omega}) - Q_{c,A}] \right. \\ & + p \left\{ p \{ \psi, \rho[\phi(\mathbf{Z}L_P)], \gamma(L_P) \} [\alpha(L_P)Q_{p,B}^F(S_B, K, L_B, L_{h,B}; \boldsymbol{\Omega}) - Q_{c,B}^0] \right. \\ & + (1-p) \{ \psi, \rho[\phi(\mathbf{Z}L_P)], \gamma(L_P) \} [Q_{p,B}^0(S_B, K, L_B, L_{h,B}; \boldsymbol{\Omega}) - Q_{c,B}^0] \} \\ & \left. \left. + I - W_h L_h - \mathbf{P}'_x \mathbf{X} \right\} . \end{aligned} \quad (4.20)$$

The first order condition for optimal allocation of labor to fire prevention measures is:

$$\begin{aligned} & \left(\frac{dp}{d\gamma} \frac{d\gamma}{dL_P} + \frac{dp}{d\rho} \frac{d\rho}{d\phi} \frac{d\phi}{dL_P} \mathbf{Z} \right) [(U^F - U^0) + \lambda(Q_{p,B}^F - Q_{c,B}^F - Q_{p,B}^0 + Q_{c,B}^0)] \\ & + p \left(\frac{dU^F}{d\alpha} \frac{d\alpha}{dL_P} N + \lambda P Q_{p,B} \frac{d\alpha}{dL_P} \right) \\ = & p \left(\frac{dU^F}{dN^F} \frac{dN^F}{dL_P} + \frac{dU^F}{dL_P} + \lambda P \frac{dQ_{p,B}^F}{dL_P} \right) \\ & + (1-p) \left(\frac{dU^0}{dN^0} \frac{dN^0}{dL_P} + \frac{dU^0}{dL_P} + \lambda P \frac{dQ_{p,B}^0}{dL_P} \right) + \lambda \frac{dQ_{p,A}}{dL_P} . \end{aligned} \quad (4.21)$$

The household will engage in fire prevention up to a point in which the marginal net benefits of diminishing risk plus the marginal benefits from increasing self-protection (α) given the level of risk equalize the expected opportunity cost of leisure, NTFP collection and production of A and B crops. However, a corner solution may exist: the household will not engage in fire prevention if, for $L_p = 0$, the left hand side of the equation is lower than the right hand side.

As collective action likelihood ϕ increases because of an exogenous increase in social capital and trust \mathbf{Z} , marginal benefits of allocating labor to fire control increase as well. However, also the opportunity cost of not allocating labor to productive investment increases, providing more incentives to free ride. Collective action theory predicts that trust, social capital, cooperation and reciprocity change in the same way, explaining both collective action successes and failures (Ostrom, 2010). Thus, in our framework, marginal benefits of cooperation should be higher than the marginal costs of free riding.

4.3. Econometric model

In this section we test empirically the theoretical findings of the previous section. Specifically, our expectation is to reject the null hypothesis that when trust and social capital are high, then L_p decreases.

Moreover we expect that social capital and trust will play a role more important than other variables in determining fire control. This will be done estimating the following relations that are reduced form of equation 4.21:

$$Pr(L_p = 1) = \frac{e^{\mathbf{X}_p' \boldsymbol{\beta}}}{1 + e^{\mathbf{X}_p' \boldsymbol{\beta}}} \quad (4.22)$$

and

$$Pr(L_p = n_p) = \frac{e^{-\mathbf{X}_p' \boldsymbol{\beta}} (\mathbf{X}_p' \boldsymbol{\beta})^{n_p}}{n_p!} \quad (4.23)$$

Equation 4.22 is estimated using a probit model where $\boldsymbol{\beta}$ is a vector of parameters to be estimated, \mathbf{X}_p is a vector of independent variables and L_p is a binary dependent variables corresponding to each one of the five fire control measures that can be implemented by farmers, i.e. clearing firebreaks, adopt backfire, burn in the later colder hours of the day, burn after the first rains and alert the neighbors before burning. Equation 4.23 is estimated using Poisson models where L_p is approximated by the count (n_p) of the number of daywork devoted to build firebreaks and by the number of fire control measures implemented by the household.

4.3.1. Data

The dataset used for the econometric estimations was provided by Sustainable Amazon Network (RAS)² database.

Data was collected between April 2010 in terms of August 2011 in Santarem-Belterra and Paragominas. The two regions differ both history, land use and biophysical characteristics. The first was already a center of pre-Colombian civilizations, while Paragominas has been founded in 1959.

The socioeconomic data we use have been collected along with ecological data³. A nested sampling design has been used, by watershed and by deforestation gradient, mapping all smallholders property in each catchment and randomly selecting a maximum of 20 properties with at least one hectare producing in 2009. Some other farmers were sampled based on ecological study transect defined to collect ecological data.

Data for price variables are kriging estimates kindly provided by Thiago Morello (Morello, 2013).

4.3.2. Estimation models

Before going for model identification some econometric issues need to be addressed, namely, the temporal inconsistency of data, the endogeneity of non timber forest product collection and the specification of the model.

Data have been collected between 2010 and 2011. When questions are not retrospective (i.e. do not span over a period longer than one year), data refer to the data collection period or to the last agricultural production season. Specifically, land use data refers to 2009 and to the burning activity of end 2008. Data concerning firebreaks are available for 2008. However all others data, either dependent or independent variables, refer to the data collection period.

In estimating the models concerning the implementation of firebreaks and the time allocated to firebreaks we assume that those variable are stable across 2008 and the data collection period. Since building firebreaks is a labor intensive activity depending on the size of the agricultural plot we assumed time consistency only between the dependent variables and the land use data. This may be problematic

² Sustainable Amazon Network (*Rede Amazonia Sustentavel*, c.f. <http://www.redeamazoniasustentavel.org/>), is the result of a huge undertaking by more than 30 research organization that decided to cooperate on an interdisciplinary ground in order to assess the land-use sustainability in the Brazilian Amazon.

³ Further information on sampling design, data collection process, the context of the study and the RAS project are discussed in Gardner *et al.* (2013).

for a causal interpretation of the models⁴ because, considering the typical feedback between collective action outcome, social capital and trust, coefficients in those two models may represent effects rather than causes.

In the theoretical model we assume that the decision to allocate labor to NTFPs collection is simultaneous to the choice of allocating labor to fire control measures. This means that the amount of consumed NTFP is endogenous. When an endogenous regressor is erroneously included in the model, estimates are distorted and biased, and a two stage instrumental variable procedure is needed (Wooldridge 2002).

Unfortunately we don't have adequate instruments available. Replicating the model used in Bowman *et al.*, (2008) with available data we only found weak correlations, a clear symptom of weak instruments. Adopting a 2SLS estimation with weak instruments, 'the cure can be worse than the disease' (Bound *et al.*, 1993; 1995): estimated coefficients are not unique and can produce inconsistent standard errors. As far as the author knows, there are no diagnostic tests for weak instruments available for non linear models (i.e. probit) (Stock *et al.*, 2002), and there are no routines available to test weak instruments in models with binary first stage and Poisson second stage as we would require. In order to get more robust estimates we chose to drop the variable related to NTFP collection.

Table 4.1 show the choice of proxy variables.

Seven models have been estimated using as independent variable five fire control measures, the amount of work dedicated to building firebreaks and the number of fire control measures adopted. The five fire control measures concerned are building firebreaks, implement backfire (burn against the wind), alert neighbors before burn, wait for the last, colder hours of the days with less wind, and wait for the first rain before burning in order to have a damp environment around the burnt plot. All the above fire control measures are labor intensive, either in terms of labor to implement the fire control measure or in terms of not achieving a good burn, and need to invest more work in order to chop logs and manually remove weeds (Carmenta, 2013).

We identified a unique pattern of independent variables $\mathbf{X_P}$ explaining all five fire control measures and the two proxies for fire control intensity (Table 4.1).

An ad-hoc dataset was prepared for each estimated model because of missing data, however little variability exists between the samples used to estimate each

⁴ It should be emphasized that the empirical models estimated here are not to be considered as causal models, but essentially as counting frequency in the sample. Moreover there is no ambition to infer results beyond the sample to a larger population. In this study generalization of results is only made up by triangulation.

Table 4.1: Description of the independent variables

Proxy	Variable name	Expected sign
Prices		
Manioc flour price	manioc_flour_price	(+)
Black pepper price	pepper_price	(+)
Dependence on agricultural income		
Receive governmental subsidies/transfers (0/1)	gov_transfer	(+/-)
Social capital		
Participate in the religious community(0/1)	church	(+)
Number of associations in which participates	n_association	(+)
Trust in neighbors		
Quality of neighbors rank [1,3]	neighbors_trust	(+)
Received neighbor help in agricultural tasks including fire (0/1)	neighbors_help	(+)
Fire prevention courses		
Whether the farmer ever experienced trainings on fire prevention (0/1)	training	(+)
Education		
Education level of the household head equal or above secondary education (0/1)	education	(+)
Demographic household features		
Number of children aged 0 to 14.	n_children	(-)
Number of man in working age: 15 to 59	n_men	(+)
Land-use/landscape flammability		
Area of primary forest in 2009	a_pri_forest	(-)
Area of secondary forest in 2009	a_sec_forest	(+)
Area of pastures in 2009	a_pasture	(+)
Area of annual crops in 2009	a_annual	(+)
Area of perennial crops 2009	a_perennial	(+)

model, and comparability among results seems to not be affected. Table 4.2 report summary statistics for variables from the ‘after_rain’ dataset. Similar Tables for the other dataset are reported in Appendix C.

In accordance to the Brazilian law (Law 8.629/93) we defined smallholders as those owning a property under four fiscal modules, that account for 100 hectares in Paragominas and 300 hectares in Santarém. For this reason there are households in the sample with up to 200 ha of primary forest. However property size can diminish down to 1 ha, and land use proxies consequently show a high variability.

In this dataset farmers adopted on average 2.9 fire control measures out of the five types considered; 81% of households report to build firebreaks, spending on average 5 days working on it. The most implemented practices after firebreaks clearing are backfire (63%) and alert neighbors (81%). In contrast, only 7.5% of

Table 4.2: Summary statistics: after_rain dataset

Variable	Mean	Std. Dev.	Min.	Max.	N
<i>Dependent variables</i>					
firebreaks_01	0.818	0.387	0	1	110
backfire	0.632	0.484	0	1	133
alert_neighbors	0.813	0.391	0	1	134
after_rain	0.552	0.499	0	1	134
late_hours	0.075	0.265	0	1	133
firebreaks_days	4.527	5.343	0	30	110
n_fcm	2.815	1.232	0	5	108
<i>Independent variables</i>					
manioc_flour_price	1.178	0.33	0.541	1.601	134
pepper_price	3.237	0.428	2.623	4.206	134
gov_transfer	0.739	0.42	0	1	134
church	0.659	0.46	0	1	134
n_association	1.022	0.78	0	3	134
neighbors_trust	2.792	0.451	1	3	134
neighbors_help	0.067	0.251	0	1	134
training	0.216	0.413	0	1	134
education	0.067	0.251	0	1	134
n_children	1.478	1.805	0	10	134
n_men	1.5	1.273	0	6	134
a_pri_forest	16.249	29.102	0	200	134
a_sec_forest	19.166	20.996	0	119.13	134
a_pasture	5.999	12.699	0	95.600	134
a_annual	1.835	1.753	0	10	134
a_perennial	0.468	1.371	0	12.5	134

farmers use to burn in the late coolers hours of the day with less wind.

Households on average are composed by the same number of children (1.48) and men (1.5) in working age, and only 6.7% of the household-head holds a secondary degree. The number of working men is a proxy for labor availability to the household. The number of children is a proxy for the number of inactive member of the household demanding care and expenditure, an opportunity cost with respect to the implementation of fire control. We haven't included the elderly because they usually receive a retirement pension, and they can contribute by hiring dayworkers. Since we don't have enough data to control for hired laborers we didn't considered them in the model. Indeed 73% of farmers included in the sample receive cash transfer from the government, either in the form of Bolsa Familia, either in the form of retirement or deficiency pension. This is a sign of poverty, but also of cash availability.

Social capital proxies indicate that there is high participation in religious activities, and that on average each household refer to at least one association. Trust in neighbors is high, but reciprocity in agricultural practices is low, less than 10%. More than 20% of respondents have attended courses on fire use and fire fight either from government agencies or from NGO's such as IPAM⁵.

4.3.3. Estimation results

All estimate details and average marginal effects for probit models are reported in Appendix C. Table 4.3 shows estimation results for participation in the five fire control measures. Table 4.4 refer to estimates concerning the intensity of the fire control measures implemented.

Some variables are omitted to ensure convergence of ML estimators, because they were perfectly predicting outcome, and need to be dropped. Summary statistics report the number of observation, the pseudo⁶ R^2 , and the p-value resulting from the χ^2 test for joint significance of all variables. The pseudo R^2 is sometimes very low, however the goal of this study is not the identification of a predictive model for engagement in fire control measures, rather is to test the relevance of social capital and trust in this choice. For this reason we privilege a low χ^2 test p-value and consistency of estimates.

Proxies for social capital and trust are often significant and always positive (with only two exceptions, but coefficients are close to 0). Participation in church activities and the number of associations in which the household is involved are significative on three fire control measures. Moreover in some cases those variables had to be dropped because they perfectly predicted outcome, this is the case for the third and the fifth models. Trust in the neighborhood is particularly important, especially for the intensity of participation in fire control. This variable is significant on five models over seven, indicating that the neighborhood is the most important level at which collective action takes place.

Coefficients for price variables are often significant and positive, because as the value of crops increase, then the value of a reduced risk or of a higher protection increase as well. However signs are sometimes unexpected as in the `late_hours` model.

⁵ The '*Instituto de pesquisa ambiental da Amazônia*' is an NGO and research institute working since 18 years for sustainable development in the Amazon. <http://www.ipam.org.br/>

⁶ The pseudo R^2 presented in all Tables is the Mc Fadden's R^2 that can't be interpreted as the standard OLS R^2 (share of explained variance over total variance). Mc Fadden's R^2 is the ratio between the log likelihood of the full model and the log likelihood of the null (the model with only the constant term). It range between 0 and 1, and represent the level of improvement with respect to the null model.

Table 4.3: Summary Table: estimates results for participation in setting fire control measure

	Probit				
	firebreaks (0/1)	backfire	alert_neighbors	after_rain	late_hours
manioc_flour_price	0.884	1.372***	1.259**	1.009**	2.048
pepper_price	1.122**	-0.259	1.120**	0.797**	-5.794**
gov_transfer	-0.039		-0.464	0.523*	1.420
church	0.308	0.599**	0.689**	0.067	0.011
n_association	0.393*	0.187	-0.045	0.306*	
neighbors_trust	1.094***	0.504*	0.589	-0.094	2.772*
neighbors_help	0.114	1.258**		1.149	0.535
training	-0.095	0.029	0.542	0.483	1.995***
education		0.048	-0.206	0.207	1.370
n_children	-0.064	-0.020	-0.061	-0.007	-0.741***
n_men	0.058	-0.140	0.180	0.066	-0.167
a_pri_forest	-0.004	-0.008	-0.004	0.005	-0.273***
a_sec_forest	0.018**	0.030***	-0.005	0.000	-0.008
a_pasture	0.000	0.032**	-0.026**	-0.013	0.127***
a_annual	0.014	-0.070	0.192**	-0.015	-1.086***
a_perennial	0.377*	0.068	0.032	0.130	1.076***
Constant	-7.560***	-2.737**	-5.908***	-4.447***	4.043
Pseudo R^2	0.269	0.186	0.303	0.230	0.755
N	110	140	137	134	164
χ^2 test (p-value)	0.0030	0.0053	0.0008	0.0009	0.0001

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 4.4: Summary Table: estimates results
for intensity of fire control measures

	Poisson	
	firebreaks (days)	n_fcm
manioc_flour_price	-0.006	0.585***
pepper_price	0.107	0.162*
gov_transfer	0.133	0.022
church	0.358*	0.135
n_association	0.143*	0.059
neighbors_trust	0.816***	0.374***
neighbors_help	0.212	0.314**
training	0.178	0.114
education	-0.203	0.089
n_children	-0.153***	-0.032
n_men	0.063	0.020
a_pri_forest	-0.002	0.000
a_sec_forest	0.002	0.003
a_pasture	0.007	0.002
a_annual	0.195***	0.017
a_perennial	-0.015	0.022
Constant	-2.110*	-1.588***
Pseudo R^2	0.211	0.071
N	110	108
χ^2 test (p-value)	0.0000	0.0000

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

The presence of governmental transfer has little or no effect on the decision to set L_P . With the important exception of the late_hours model, fire management training has also little effect. However we may expect that some of the effect of trainings feedback on social capital and neighbors trust because after trainings there are more reasons to expect higher fire control by other farmers. Education is never significant, however it has been dropped from the first equation because it perfectly predicted success.

The demographic composition of the household is almost never significant, showing that the labor constraint is probably not binding. However the number of men in working age is quite sensitive to the functional form definition: the

logarithm of n_men , reflecting decreasing marginal productivity of labor, is highly significant in explaining the number of days allocated to building firebreaks and the decision to burn after the first rain⁷.

Although the option to include the logarithm of n_men would have increased coherence with the theoretical model we have chosen to drop it because it would have largely reduced the number of observation available, transforming into missing all observations for $n_men=0$, whose logarithm goes to minus infinite.

The effect of land use and landscape type reflects technical parameters involving the efficacy of fire prevention measures relative to landscape type and flammability. Indeed those variables affect the decision to engage in fire control measures, but have little or no effect on the intensity of fire control.

When primary forest cover is high, then fires are less likely to spread out of the plot and there are lower incentives to adopt backfire or to burn when wind is low because since risk is already low there are little marginal benefits in further reducing risk. This effect became ambiguous when the area of secondary forest increase. Secondary forest still provide a protection from fire contagion, but when it burns fire can have more disruptive effects. In pasture dominated landscapes, the most flammable one, farmers are more prone to set fire control measures, in particular backfire and burn in late hours. Indeed, as reported in interviews, strong wind makes very difficult to control fires in pastures. Increasing the size of annual plots increase the needs for firebreaks and alert neighbors, on the other side burning in the late hours of the day is not practiced. This may reflect two different ways to burn: in pastures firebreaks are less effective, and even if wind is low, weeds burn. Moreover, since pastures are often large, neighbors control is more difficult. This is the opposite of what happens in annual crop plots, which are smaller, and firebreaks as well as human supervision is more effective. Moreover since larger logs need to be burnt, but flames are likely to be smaller, farmer are used to burn in windy hours.

Perennial crops are rare, and plots are small (see Table 4.2), however when perennial crops increase farmers are more likely to control fire in pasture and *roça*, implementing more firebreaks and burning in colder hours.

It can be argued that important effects related to exogenous fire risk are omitted from this model. Indeed the survey has been carried on in two far Municipaplties (Santarem and Paragominas) for which exogenous risk, especially related to climatic conditions may variate. We couldn't include that dummy in the model because of high collinearity with prices. Indeed as shown in Table 4.5,

⁷ Appendix C provide estimates results using the logarithm of n_fcm

almost all of the variance in Paragominas dummy is explained by prices.

Table 4.5: Probit estimation of Paragominas (0/1)

Variable	Coefficient	(Std. Err.)
manioc.flour_price	-10.761***	(2.164)
Victim of external fire accident?	0.262	(0.887)
Intercept	10.032***	(2.233)
<hr/>		
N	222	
Pseudo R^2	0.939	
$\chi^2_{(3)}$ p-value	0.0000	
Percent of dependent variable correctly predicted	99.55%	
<hr/>		
Significance levels : * : 10% ** : 5% *** : 1%		

4.3.4. Discussion and conclusion

Including variables of social capital and trust we found different estimates from those by Bowman *et al.* (2008). The intensity of investments in firebreaks is especially determined by social capital and neighbors trust (Table 4.4). The size of the annual plot and the demographic feature of the household are significant (see also Appendix C), but prices are not significant.

Fire management training has little or no effect on the decision to set fire control measures. The effect of land use and landscape type reflects technical parameters involving the efficacy of fire prevention measure relatively to land use and landscape flammability. Indeed these variables affect the decision to engage in fire control measures, but have little or no effect on the intensity of fire control.

Variables concerning social capital and trust are likely to positively affect the decision to engage in fire control measures, and the intensity of fire control. Other studies are not conclusive on this (Carmenta *et al.*, 2013; Simmons *et al.*, 2002), perhaps because of a mis-specification of variables due to the difficulty to indentify the right level in which collective action takes place. As we shown both social capital proxies at the community level as well as in neighborhood level are often significant. This support the thesis that interdependency in fire control exist, and that insufficient incentives to control fire may come not only from excessive costs or lack of knowledge (as in Nepstad *et al.*, 1999 or Carmenta 2013), but from a collective action failure at the local level.

Chapter 5

Eliciting mental models: is collective action perceived as an option by farmers?

5.1. Introduction

In previous Chapters we have discussed the relevance of collective action in the decision to control fire, the factors that may obstacle its likelihood and the importance of institutional arrangements. We have also noticed the importance of situational framing in determining whether it is worth or not to set up fire control measures.

With the increased occurrence of accidental fires (Sorrensen, 2009), the perception of the need to control fire may be changing and may eventually lead to new rules and norms (Brondizio and Moran, 2008).

In this Chapter we deepen the role of framing and in particular of actor's mental models with respect to fire issues. How do perceptions about risks and of norms about fire control and firefight affect perceptions about governance preferences, fire use or a transition out of fire use? Is collective action indeed perceived as an option by farmers, or is controlling fires seen only as a government task? How may policies for collective action deal with those preferences?

To address this question we sketch a framework based on Denzau and North's (1994) mental models and Bromley (2006) concept of Volitional Pragmatism. Moreover we discuss the potential benefit of approaching collective action through mental models. Then we apply a socio-psychology method named Q methodology to elicit farmers' mental models, and we test three hypotheses about mental models heterogeneity. In the end we discuss results and the implication for policies

for collective action.

5.2. Theoretical framework, context of the study and methodology

5.2.1. Actors' risk framing and collective action

Risk and uncertainty linked to fire, when addressed from a collective action perspective, imply several particularities. Rational choice theory considers that failure or success of collective action depends on how an individual rationally infer the costs and the benefit of engaging in this action (Coleman and Coleman, 1994; Olson, 1965). But when individuals face a situation distinguished by structural uncertainty such as risk mitigation, actors' capacity to infer outcomes from past actions is seriously challenged. The certainty of future benefit and the ability to provide local enforcement are important factors influencing the success of collective action (Agrawal and Ostrom, 2001). Trust is often seen as the main tool to defeat structural uncertainty, but developing trust depends on a costly process (Dasgupta, 1988; Ostrom, 2000) involving beliefs and institutions (Bromley, 2006; North, 2005). External governance (either in terms of provision of information or of monitoring and control activities) can thus be important to build institutions that favor engagement of actors in risk control, by suggesting rules which reduce uncertainty and offer a frame for outcome predictability, favoring trust relations (Agrawal and Ostrom, 2001; Dasgupta, 1988).

The difficulty in assessing risk leads to a wide variety of perceptions regarding the possible effectiveness of practices and thus of the outcome of collective action (O'Connor *et al.*, 1999). Gruev-Vintila and Rouquette (2007) show that risk-prone behaviour depends on personal involvement in risk, which is influenced by the perceived magnitude of the risk, personal exposure to risk and perceived capacity to mitigate risk. In cases where risk is endogenous to a group (i.e. the neighborhood), the higher the personal involvement, the more certain the collective action solution, and the lower the perceived magnitude of risk. Conversely, the more risk is perceived as exogenous to the reference group (i.e. external to the neighborhood), the lower the personal involvement in risk control and the perceived likelihood of collective action. The perception of risk thus seems to have a great influence on the possible engagement of an individual in collective action. Increased perceptions of fire risk are likely to increase the costs of organization, especially if involvement in risk is low. Understanding actors' attitude to risk is

crucial when defining the appropriate governance setting.

Mental models have been increasingly used as a conceptual framework to analyse actors' cognitive frames, norms and collective action for natural resource management (Jones *et al.*, 2011; Lynam *et al.*, 2012; Eisawah *et al.* 2013, Wolfe (2012) and Boschetti *et al.* (2012)). Mental models are made up of experience and culture (Denzau and North, 1994); they are the joint product of rule-based stable thinking and ephemeral knowledge (Jones *et al.*, 2011); and they are fed by empirical information through abductive learning (Hodgson, 1993). Actors' mental models shape how actors perceive the payoffs of collective action and thus the expected benefits to engage in it (Denzau and North, 1994). Mental models also influence the form of institutional structures and the emergence of norms:

‘Mental models are the internal representations that individual cognitive systems create to interpret the environment; institutions are the external (to the mind) mechanisms individuals create to structure and order the environment’ (North, 1994).

In North's works, however, it is not clear how a consensual mental model is formed and selected to choose an institutional solution (Schlüter, 2009). Bromley's sufficient reason framework provides a solution to this problem as it links individual agency and collective action (Schlüter, 2009).

In Bromley's view (2006; 1989), to find a solution to a problem characterized by structural uncertainty, the actors must have a sufficient reason to change, and engage in the collective action process that culminates in choosing among competing solutions and norms. The construction of arguments leading to a sufficient reason not only depends on cognitive models (Denzau and North, 1994) but also on normative ones. Cognitive models comprise settled and warranted beliefs. Settled beliefs are based on experience and previously used patterns, while warranted beliefs rely on knowledge provided by authority, experts, science and the media the actor considers to be reliable. Normative models consist in valuable beliefs based on personal values, the volitional premises to change. Both normative and cognitive models follow an abductive updating process and depend on communication with other individuals (Bromley, 2008). Bromley's concepts of sufficient reason and volitional pragmatism bring us back to individual agency and make it possible to open the black box of how individual reasons lead to choose the institutional settings (Bromley and Cernea, 1989; Schlüter, 2009).

The importance of shared mental model (actually low heterogeneity of perceptions and a common knowledge of the resource) has been acknowledged in collective action theory as reducing social uncertainty increasing incentives to

cooperate (Jorgerson and Papciak 1981), and reducing the perceived cost of organization (Ostrom 2009, Olson 1956, Heckathorn 1993). In other word before deciding whether to cooperate or not, actors need to identify the problem, a set of solutions and agree that cooperation can be a solution, holding a similar representation of the situation (Simon and March 1958). Metha *et al.* (1999) proof this to be key for actors social and institutional positioning. While heterogeneity on normative issues linked to differences in identity and interests have already been addressed (Baland and Plateau 1999) studying collective action by mental models open the road to individuate a further class of conditions for a successful collective action related to the cognitive component of mental models.

Recent studies on mental models concentrated on identifying the origin of mental models and the methods to elicit them (Jones *et al.* 2011). We believe there are useful complementarities in bridging collective action and mental models studies. This complementary approach has more explanatory power as social and environmental uncertainty became more relevant for collective action. We tested the hypothesis that consensus exist across mental models, at least on a set of issues (Hp1) and that farmers share mainly the same set of normative and cognitive model. (Hp2). In the end we used Bromley's framework to explore farmers' mental models, to understand what arguments they have built in relation to fire risk and fire control; to what extent the reasons they carry on may make them defeat structural uncertainty (Bromley, 2008), create (or not) endogenous effective institutions to mitigate fire risk through collective action, and how policies could support collective action as a solution to the fire control dilemma. In particular we looked if regularity exists between perceived fire risk, risk involvement and a preference for collective action (Hp3). Indeed, increasing perceived fire risk is likely to increase the costs of organization, especially if involvement in risk is low.

5.2.2. Context of the study

We sampled 16 communities in two neighboring municipalities, Paragominas and Ipixuna do Pará, both located in the post-frontier region of Pará state. Those two municipalities embrace different landscape type and a number of traditional as well as recent communities. Moreover, in recent years, the two municipalities applied opposite policies against fires (see Chapter 2).

During a two-month field study in 2013, we visited 16 communities of these two municipalities in both traditional riverside areas (n=4) and in more recent land reform settlements (n=12).

See Chapter 3 for a further description of the context of the study.

Table 5.1: The communities involved

Region	Characteristics	# Communities	# Interviews
Paragonorte	Land reform settlement	4	23
	Degraded pasture		
Mandacaru	Land reform settlement	1	2
	Pasture		
Capim	Riverside communities	4	9
	Dominated by forest		
Luiz Inacio	Land reform settlement	3	11
	Dominated by forest		
Ipixuna	Land reform settlements	4	10
(around Gleba 13)	Mixed, dominated by pastures		

5.2.3. Data collection and analysis

In order to assess mental models regarding fire use and control, we interviewed key actors identified with the help of community leaders and local organizations among the farmers who hold a key position with respect to fire issues, either for organizational or geographical reasons. Key actors included for example innovator or entrepreneurial farmers, producers who had suffered serious damage caused by fires, or who used original strategies to control fires. Conducting interviews on fire accidents was challenging; the fire issue is taboo as it is a latent source of conflicts in the communities. Some farmers even told us that the interview was the first time they had spoken out loud about fires. For this reason, we combined a semi-structured interview to gather general information on the respondents, their farms and on how fire was managed at the community or neighborhood level, with a socio-psychology method named Q methodology, to reveal mental models.

Q methodology was born from the work of Stephenson (1935) in psychology; it was popularized in political science by Brown (1980) and used in various other social sciences including environmental policy and economics (Baker *et al.*, 2006; Barry and Proops, 1999; Ockwell, 2008). Data collection consists in asking the interviewee to rank statements in a constrained quasi normal score distribution (Table 5.2), and to comment the resulting patch. This enables the respondent to take a position even on uncomfortable issues, taking advantage of the constrained distribution of the scores to be allocated among statements. As far as the author know Q methodology has not yet been used to study mental models however we believe it can fit this purpose, especially relating to uncomfortable or taboo issues. Even if respondents had to give a representation of their thoughts through a limited number of statements, they had the opportunity to explain their choices

and further detail of their understanding in the semistructured interview. Indeed Q methodology fit the requirements for a direct elicitation method as classified by Jones *et al.* (2011)

A cross-correlation matrix of all sorts (individual mental models) is then factored to distinguish the main shared mental models (SMMs) among respondents (see for instance (Davies and Hodge, 2007; Ockwell, 2008)).

Table 5.2: Constraint table used to rank the opinion statements

			0	
	-1		0	1
	-1		0	1
-2	-1		0	1
-2	-1		0	1
Strongly disagrees	Disagrees	Neither agrees nor disagrees	Agrees	Strongly agrees

We applied the Q methodology individually using a game board and cards (Table 5.1), as this interactive tool helps gain the confidence of smallholders and results in more answers than would be possible with a questionnaire. The 55 respondents were asked to rank 17 statements on a 5-steps scale. The selection of statements was based on existing literature and previous interviews and group work in the Paragominas communities already carried out. We selected statements concerning normative and cognitive models about slash and burn and the risk of fire spread, the norms applying to fire control, fire fighting and fire use in the neighborhood. These statements also concerned perceptions related to the governance level at which fire should be controlled (individual, community or government action). We deal with a sample characterized by a low literacy level: despite the use of an interactive set, with a board and cards, the test was generally administered orally, needing on average half an hour. In four cases the interviewees were not able to accomplish the test and were dropped from the sample. Barry and Proops (1999) suggest an optimal selection of 36 statements, but we had to reduce it to 17 to reduce the time needed to accomplish the test. Some statements were dropped and some others were connected to not omit important representations. Q methodology does not require perfect independence between statements, and we tried to mix up statements following farmers common sense. Indeed statements were tested and adapted to ensure optimal comprehension by the respondents.

Data from the Q methodology was analysed following the procedure described in Brown (1980), which enabled to distinguish SMMs, seen as a particular com-

Figure 5.1: A farmer accomplishing a Q test



bination of agreements and disagreements regarding the statements. A Q sort (individual mental models) cross-correlation matrix was factored using the principal component method; a varimax rotation was applied since no reasonable criterion to legitimize a judgemental rotation was found. Four groups were individuated by three criteria: eigenvalue had to be greater than one, a minimum of 4 sorts had to load significantly on each factor, and at least five distinguished statements had to emerge in order to guarantee interpretability (see Table 5.3). Sort significance was set at 1% in order to load only the sorts that really described the factor. Factor scores were obtained averaging the Q sorts belonging to the factor utilizing the weight $f/(1 - f^2)$, where f is the factor loading. Significant statements are individuated testing non-zero differences among each factor score. Other technical details are reported in Appendix C. Hypothesis 1 is refuted for a certain statement if the statement is not significant on any factor, or signs differ. Hypothesis 2 is tested computing the eigen value ratio between two sequent factors. If the eigen value ratio is higher than 3 we can assume a good degree of consensus on the first factor (Stone–Jovicich *et al.* 2011). Statistics of farmers features whose sort loaded significantly on each factors were also computed to

reveal the possible explanation of farmers SMM's. The link between the features of respondent loading on a SMM and the corresponding factor does not allow any inductive generalization, especially due to the limited size of the sample used in this study. Nevertheless, if strongly supported by other data on participant observations and semi-structured interviews, complementary statistics can be used to adduce explanation to the SMM. Since independence holds among factors, the SMM identified through the Q-methodology by this sample have statistical validity (Barry and Proops, 1999; Brown, 1980). Many studies on the elicitation of mental models use consensus analysis (Jones *et al.*, 2011), and assume that factors identified in the sample represent all the relevant SMMs in the action arena (Stone-Jovicich *et al.*, 2011). With Q methodology, instead, other relevant latent SMMs may exist, but the validity of the identified factors is not influenced by the sample size (Brown, 1980).

5.3. Results

The Q-test (Table 5.3) enabled the identification of four main SMMs, held by 34 farmers (out of the 55 interviewed)¹. Table 5.4 characterizes the farmers loading on each SMM with features relating to region, farming system, experience of fire accidents, and social involvement.

5.3.1. Mental models elicitation

SMM A: Eager to shift to alternative techniques

SMM A, endorsed by 14 farmers, expresses the point of view of farmers willing to engage in a transition away from the use of fire (S3). Fire is no longer the only way to produce (S1) and is probably not the best way (S2). Burning is no

¹ 34 sorts (individuals) loaded significantly on 4 factors (SMMs), accounting for 55% of total variance. In Table 5.3 values for each sentence correspond to the standardized mean value of the score given by the individuals loading on this factor. Answers can range from -2 to 2 (ordinal), -2 indicating major disagreement, -1 relative disagreement, 0 neither agree nor disagree, +1 relative agreement and +2 major agreement. Thus, for statement 9, the Table reads: 'SMM A strongly agrees, SMM B mildly disagrees, SMM C relatively strongly disagrees and SMM D relatively agrees.' Asterisks reflect distinction between statements among factors (* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$). A statement is considered to be distinct within a factor if the corresponding parameter is significantly different from the parameters corresponding to the same statement on all the other factors. For any single statement, standardized z-scores between two factors are significantly different if their difference is greater than $z \cdot \text{SED}$. SED is the standard error of differences, which is a single value for each pair of factors (Brown, 1980). For instance, for sentence 9, all SMMs are significantly distinguished; for sentence 10, only SMM A is distinct from other SMMs.

Table 5.3: Identification of four SMM, based on a Q test. Values correspond to standardized mean scores for each statement, asterisks indicate most distinct statements

	Statements	SMM A	SMM B	SMM C	SMM D
fire use	1. Slash and burn is the only way to produce, and I think that there are no alternatives.	-1.69	-0.82***	-1.49	-1.66
	2. Slash and burn is a good way to produce, but it is dangerous, I have to be careful.	0.20***	1.42***	0.79***	-1.53***
	3. Slash and burn it is not a good way to produce, we need to change practices.	1.06***	-0.09	-0.04	-0.19
fire risk	4. Fire will never enter my property, it is well protected	-1.57	-1.92*	-1.32	-0.50***
	5. My property is now well protected, but in the past, accidents occurred and caused damage.	0.4	-0.78	-0.5	1.25***
	6. I am frightened a fire will come and destroy everything	0.54***	1.36***	0.01**	-0.51***
norms in neighborhood	7. My neighbors and I burn together in an organized way.	-0.34***	0.29	0.0521	0.44
	8. When my neighbor burns, I stay on my property to check for fire spread	0.28	0.34	-0.03	-0.69***
	9. I don't think burning is the right way to produce anymore, I think my neighbor should stop using fire.	1.60***	-0.29***	-1.20***	0.82***
	10. I think that fire issues are properly discussed in the community	-0.65***	0.13	0.53	0.52
fire control norms	11. Burning is a farmer's right.	-0.47*	-1.34***	1.41***	0.06***
	12. Building firebreaks takes a lot of time, I can choose whether to build them or not.	-0.92	-1.2	-1.67***	-1.41
	13. Fires should be better controlled; the community has an important role in producing rules.	1.01	-0.23***	1.08	1.02
	14. Fires must be controlled; those who do not control them must be punished.	1.51	1.46	1.42	0.57***
fire fight norms	External enforcement is highly desirable.	-0.54	1.08**	-0.65	0.35***
	15. When an accident occurs I think everybody is ready to help.	0.55	0.41	0.0417	1.86***
	16. I think people should help more during fire accidents	-0.96**	0.19	0.3	-0.40**
	17. I always help during fire accidents.				
	Variance	28%	11%	10%	6%
	Eigenvalue	15.59	6.04	5.32	3.37
	N	14	9	7	4
	Factor reliance	98%	97%	97%	94%

Table 5.4: Characterization of the farmers' loading on each SMM. Percentages indicate proportions of individuals concerned within each SMM; asterisks indicate a significant difference.

	SMM	A	B	C	D	Sample
	Number of respondents (unless specified)	N=14	N=9	N=7	N=4	N=55
Region						
Ipixuma municipality		7%	11%	43%*	0%	18%
Capim region (riverside residents)		43%***	11%	14%	0%	16%
Paragonorte & Mandacaru (Land settlement with degraded pastures)		43%	67%	14%*	75%	46%
Luis Inácio (Land settlement in forest landscape)		7%	11%	29%	25%	20%
Farming system						
Used tractor at least once		25% (N=12)	55%	71%	25%	45% (N=47)
Size of property		35Ha (N=11)	25Ha (N=6)	79Ha	32Ha	43Ha (N=43)
Dependent on agricultural income		72% (N=11)	34% (N=6)	43%	25%	58% (N=43)
Would shift to perennials if fire risk were reduced		40% (N=10)	100%*** (N=4)	57%	50%	40% (N=35)
Experience with fire accidents						
Experienced more than 2 fire accidents in the last five years		38% (N=13)	20% (N=5)	66% (N=6)	75%	48% (N=42)
Fire damage exceeded 2000 R\$ or 2 ha of forest		69% (N=13)	60% (N=5)	71%	100%	70% (N=44)
Damaged by fires originating within the neighborhood		84% (N=13)	33%* (N=6)	86%	25%*	65% (N=43)
Damaged by fires originating out of the neighborhood		31%** (N=13)	83% (N=6)	57%	100%*	58% (N=43)
Social involvement						
Talk about fires during meetings		71%	83% (N=6)	100%*	0%***	70% (N=46)
Participated in at least one training course in the last 5 years		67% (N=12)	67% (N=6)	85%	25%	59% (N=44)
President of local association		57%***	22%	14%	0%	29% (N=55)
Pessimistic outlook		14%	0% (N=6)	29%	75%***	23% (N=47)

Significance level (* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$) corresponds to a binomial-test of non zero difference in means between factor and sample. Means are calculated as the probability of the farmer feature conditioned on the farmer loading on the related factor. For instance: the probability of being from the Capim region and loading on factor A is of 43%, which is significantly different ($p < 0.01$) from the probability of being in the sample (16%).

longer the farmers' right (S11), and these respondents insist that their neighbors should stop using fire (S9). They perceive fire risk as being high (S4, S6) but fire prevention measures as being reliable (S5). Fire control is a moral obligation and not just an individual choice (S12). For this reason, there is a preference for the enforcement of rules: the community has an important role to play (S13), but maybe because of a low level of cooperation in the neighborhood (S7), government intervention is considered to be indispensable to solve the fire control problem (S14). Firefighting is not perceived as being as useful (S16), and these farmers are generally not involved (S17).

This SMM is most representative of the farmers in 'traditional' riverside communities (Table 5.4), who live in the best conserved areas. This may seem surprising, as despite their traditional origins they show a high degree of willingness to engage in an agricultural transition. New technologies are quite attractive to these farmers, as they learn about tractors and other alternative techniques on the television, radio and through assistance from technicians, but in practice, have little access to them. Those farmer present a high level of involvement in risk: they suffered damage from fires which mainly escaped from neighboring properties (Table 5.4), which is logical given the low probability of contagion from afar in the still relatively preserved forests. For the same reason they perceive that fire control measures can be reliable (S5). Moreover the magnitude of losses is for them higher than for farmers loading on other factors (Table 5.4).

SMM B: Favorable to fire use but perceives a high fire risk

SMM B is oriented towards traditional fire use: fire is a good way to produce, but it has to be controlled (S2), building firebreaks is a moral duty (S12), although they are not really a reliable prevention measure (S5). In SMM B, perception of fire risk is by far the highest of all the SMMs (S4, S6). Indeed, 83% of these farmers have experienced accidents caused by fire originating outside their neighborhood (Table 5.4). Most farmers grouped under SMM B come from the land reform settlements with degraded pasture. Open pastures are highly inflammable and can carry fire over several dozen kilometres. These respondents declare that if there were no fire risk, they would plant profitable perennial crops, but given the context, they prefer continue swidden culture using fire.

This perception of a serious threat of uncontrollable fires may explain one of the most distinguishing features of SMM B. This SMM does not show beliefs in community control (S13). These farmers are thus in favor and in some sense dependent on external help, government intervention being viewed as the only

solution to the fire problem (S14). According to this SMM, few or no cooperative activities are undertaken in the neighborhood (S7, S8) and these farmers report a low level of satisfaction concerning communication about fire control within the community (S10). They do wish there were more collective participation in firefighting, especially in emergency cases (S15). Fire is thus seen as an exogenous risk against which the community needs to act to limit possible destruction, this mental model shows a little involvement in risk, at least in fire prevention.

SMM C: Favorable to fire use because it is under control

Although SMM C acknowledges that slash and burn is not the only available production technique (S1), it shows strong preferences for fire use and fire control (S12). Fire use is a right, and nobody has the right to forbid it (S11), there is no legitimate reason to ask the neighbor to stop using fire (S9). Interestingly, 71% of these farmers have tried to mechanize at least once; mechanization is a well-known alternative, but fire is still preferred.

Although fire accidents are felt as a threat (S4), they do not appear to be a serious preoccupation (S6). One possible explanation is the good cooperation between neighbors (S7), which reduces the fire risk in the neighborhood. SMM C stresses the importance of enforcement via fire prevention rules. Moreover since they experienced mainly fire accidents in the neighborhood, SMM C shows a high level of involvement in risk.

The farmers in this SMM have almost all been trained in fire control in the past and all have already discussed fire during community meetings. This background may explain the higher level of cooperation (S7), the strength of the moral norm toward fire control (S12) and the view of the government as a partner (S14). Almost half of the respondents are from the municipality of Ipixuna do Pará where government action is stronger, and a third are from the recent land settlement Luiz Inacio, where technical assistance from Paragominas municipality has been concentrated in recent years. According to this SMM, collective action is an efficient way to control fire, and if the risk is under control, slash-and-burn is considered a better technique than other agricultural alternatives they have experimented.

SMM D: Turns to collective control or exit farming in the absence of external support

According to SMM D, fire is not the right way to produce (S2) and neighbors should stop using fire (S9), but a shift away from slash and burn is not ranked as

an absolute priority (S3). The attitude of SMM D towards risk is questioning: although all respondents have experienced serious damage due to fire spread in the past, SMM D shows no fear of fire accidents and the farmers consider themselves to be protected against future events (S5). Although most fires experienced by these farmers originated outside the neighborhood, this SMM considers that the community has an important role to play (S13). The need for cooperation in firefight is the most popular statement (S16), but there is no real confidence that the others will help (S15); the respondents acknowledge that they themselves do not cooperate in firefights (S17). This SMM can be distinguished from the others because the call for external help is significantly lower (S14).

In fact, all these farmers have been seriously damaged in the past and now appear to be disappointed; 75% of them have a pessimistic view of the future of the community (Table 5.4). They appear to have been marginalized from social dynamics regarding fire, as only one out of four respondents that load on this factor has received fire training in the past five years and none of them has discussed fire in community meetings. This attitude may have personal reasons, as three out of four do not depend on their agricultural activity: three of them have a retirement pension and the fourth has started a commercial activity on the side. But they are also all from the land settlements in Paragominas and report they are disappointed with government intervention. Thus, it seems that these farmers believe in community measures because they place no hope in external support. But when they had the opportunity they adopted an exit strategy, reducing reliance on agricultural income. Indeed they are no more involved in risk.

5.3.2. Do farmers share a common mental model?

Hypothesis 1: Consensus exists across SMMs, at least on a set of issues

All statements are significant on at least one SMM, indicating that there is high heterogeneity of thinking either on normative and cognitive models. Hypothesis one thus is largely refuted. All SMMs pointed out that fire is not the only possible technique (S1), however SMM B shows lower disagreement.

All SMMs differ in opinion about the goodness of controlled fire as an agricultural technique (S2), but with the visible exception of SMM A, they do not call for a change in practices. Statements 9 and 11 reveal high divergences in cognitive models about fire use, either in moral norms as in neighborhood norms, suggesting that conflicts for fire use are likely to occur.

With respect to fire control we found higher homogeneity of thinking, at least on normative statements such as the moral obligation to build firebreaks (S12), and other institutional measures of fire control (S7, S8). However all the SMMs evidence that fire is little or not at all discussed within the community (S10).

Although all producers perceive fire as a threat (S4 has always strong negative sign), and there is homogeneous uncertainty about fire risk (S5), there is a high disagreement regarding the destructive power of fire (S6).

Expected participation in firefight by respondents and the other members of the community is a debated issue (S15, S17), but, with the exception of SMM C, there is no normative model operating for cooperation in firefight (S 16).

Normative statements calling for enforcement of fire control rules often had homogeneous high agreement scores. Despite A, all SMMs stressed the fact that the community has a role to play in controlling fire (S13). But, with the exception of SMM D, government intervention obtained even higher scores, external enforcement being considered as a necessary condition to control fire (S14).

Hypothesis 2: Farmers share the same set of normative and cognitive model

Despite there is no consensus across mental model on any specific issue, it can be that one mental model is more representative of the sample, and that consensus converge on it. Indeed the eigenvalue-ratio between factor A and B is 2.58, close to 3, the threshold acknowledged to display consensus over the first factor (Stone–Jovicich *et al.* 2011). Moreover most presidents of local associations hold this mental model (Table 5.4), and since leaders of associations are always elected, their opinion is therefore representative of many farmers in their communities. Hypothesis 2 is rejected, but a certain degree of homogeneity exists in the sample with respect to the first mental model. According to this SMM, therefore, there is a generalized demand for external enforcement of fire control rules to reduce fire risk and eventually enable a shift to alternative solutions.

However it should be noticed that this result highly depend on the sample, and that this is not a representative one.

Hypothesis 3: Regularity exists between perceived fire risk, risk involvement and a preference for collective action

To understand how perceptions of fire risk, governance preference and risk involvement, link the four SMMs we resume them in Table 5.5. Perceptions of fire risk oppose those who feel that there is a high risk of fire accidents (A B) and those

who feel fire is under control (C–D). Risk involvement opposes those who are ready to adopt risk prone behaviour (A–C), and those who lack involvement (B–D).

Table 5.5: Risk involvement (§), perception of fire risk (†) and governance preference (‡)

Involvement in risk Perception of risk	High	Low
Low	C complementary solutions (fire control)	D exit
High	A complementary solutions (transition)	B hierarchical external governance

(§) involvement in risk is discussed in the previous section. (†) perception of fire risk is based on S4, S5, S6. (‡) perception of governance preference is based on S13, S14.

This differentiation corresponds to different preferences regarding the type of governance that leads to better control of fire. SMM D represents those who implemented an exit strategy, SMM B is unable to deal with risk, and call for a hierarchical solution. By opposite SMM C and A are more favorable to complementary governmental and internal community control. However we must take into account the opposite scores of normative statements about fire use that characterize those models. While type A is likely to undertake collective action to leverage external resources to exit fire (i.e. lobby toward the local governmental organizations and the Institute for the Agrarian Reform) the second is likely to undertake collective action for fire control. Indeed none of the farmers from Ipixuna, particularly represented in this SMM, recalls fire accidents during the two years of the program. Instead, they reported in interviews several episodes of monitoring and sanctioning among neighbors. In the words of Seu Felisardo:

‘Since two years there are no more accidents, now everybody require a license [...]. Three others and I went to check [in the neighboring properties], and we found that he [the neighbor] had not made a meter of firebreaks! We peek at him to be able to control fire anyhow [...]. Before the law [the license] nobody was building firebreaks!’

5.4. Discussion and implications for collective action

The literature stresses the importance of landscape features in defining fire risk (Cochrane, 2003; Nepstad *et al.*, 1999), but the capacity to adapt and develop effective fire control heavily influence fire risk perceptions at the local level. A certain degree of cooperation may takes place within neighborhoods to avoid fire spread among nearby properties, but the outcome of local collective action is threatened by large-scale fires caused by the lack of control over external areas. This is particularly true in highly flammable landscapes dominated by pastures and degraded forest. This point appears clearly in our study: when farmers are used to experiencing fires which originate outside their neighborhood they start accepting the phenomenon as a natural and ineluctable one, since every fire control measure they set up on their property or within the neighborhood turns out to be useless (Cammelli and Coudel, 2013). When fire risk does seem to be uncontrollable, people are less involved in risk (Gruev-Vintila and Rouquette 2007) and less likely to show fire-prone behaviour (Pégard, 2010; Winter and Fried, 2000). SMM B has the highest perception of fire risk, and has the least confidence in collective action, as fires are perceived as being ineluctable.

Risk thus appears to represent the upper bound for collective action. When fire risk is high and involvement is low, cooperation is less likely since the expected benefits of collective action are reduced. Personal exposure to risk increases, but the perceived capacity to mitigate risk decreases significantly, leading risk to be considered as natural and ineluctable. Consequently social norms to control fire risk are less likely to emerge. This mechanism operates at a cognitive level but does not appear to affect normative models about the future: although SMMs A and B both have a high risk perception, their evaluative beliefs regarding fire use are quite different. Opinions about fire use relate to a more complex set of explanations.

The different perceptions of fire risk and fire controllability lead to different preferences regarding the governance required to encourage fire control. SMM B does not believe in the effectiveness of endogenous control because fire risk is exogenous to the neighborhood, and thus prefers external control. SMM C believes in local social control, but has received support from external institutions. In SMM D, trust in community control emerged in response to a cognitive dissonance originating in the absence of external support. Although we had expected to find marked differences between traditional communities and land reform settlements,

in practice there is no clear cut distinction. It is noteworthy that apart from farmers loading on SMMs A and C, which mainly represent traditional riverside communities and Ipixuna farmers, the other SMMs are mixed within the same area. This can be explained by differences in personal and collective experience of fire (Brondizio and Moran, 2008) or in neighborhood dynamics, but may also reveal differences in accessing policies. The success of a policy to encourage collective action critically depends on the creation of a shared mental model (Jones *et al.*, 2011; Stone-Jovicich *et al.*, 2011) and thus on a universal policy access. Because of the perception of risk linked to actor's decisions, an effective policy for fire control must take into account difficulties in policy delivery: not only is social brokerage important (de Sardan, 1995), but a good understanding of mental models may be the key to effective risk communication (Morgan *et al.*, 2001).

5.4.1. Mental models collective action and policy

The link between governance preferences and perceived fire risk opens considerable scope for policy interventions aimed at legitimizing endogenous fire control, by creating awareness of the factors that influence controllability of fire risk and encourage fire-prone behaviours.

Trust cannot be taken for granted in economic and social behaviour; its production depends on institutions, and it plays a key role in ensuring predictability (Dasgupta, 1988). With a reduced budget, Ipixuna's fire prevention programme seems to have been effective in restoring trust in fire manageability within neighborhoods (Cammelli and Coudel, 2013). A combined action of fire prevention training, improved access to the licensing system, arbitration between neighbors and a few sanctions at the municipal scale made it possible to reduce the expected risk of fire from other neighborhoods, and to legitimize internal sanctions (Cammelli and Coudel, 2013). The example of Ipixuna (SMM C) suggests how risk reduction can be effective in creating shared mental models for collective action, and that perception of risk can be reduced by increasing trust in cooperation and legitimizing local sanctioning even with very few penalizing activities. Some external sanctioning contributes to start the trust building process, but the final effect on fire control cooperation cannot be attributed to external sanctioning alone. The main role of external sanctions is rather to provide a further argument to reach a sufficient reason to create a social norm for fire control: external sanctions do not only have a deterrent effect and increase the application of rules, they also legitimize local sanctioners to operate within the community and, through abductive learning, establish a horizon of predictability of outcomes over

collective action (Ostrom, 2000). All farmers from Ipixuna reported that they were certain that everybody was now controlling fire for fear of sanctions; but only one smallholder had been fined in the two preceding years. Such a compliance to the law can't be explained by such a low enforcement activity. Instead, a collective action surge within Ipixuna's communities appears to be a more likely explanation.

5.5. Conclusion

Mental models have both a cognitive and a normative component (Schluter 2009), but literature on collective action has paid little attention to the cognitive side of mental models, stressing the importance of homogeneity of identity and interests (Baland and Plateau, 1999; Agrawal, 2002). Mental models not only shape the payoffs to engage in collective action (Denzau and North 1994), they are the cognitive tools of actors such as understanding how the problem and the set of solutions are framed, and this is key for the collective action process in an uncertain environment. Addressing collective action likelihood by mental models adds a further class of conditions for a successful collective action related to the cognitive component of mental models. Those conditions are contingent to the case of study but are also inescapable to understand the local collective action process. Castillo *et al.*, (2011) found that actors' decisions in field experiments on common-pool-resources crucially depend on their previous experience and context. We believe that eliciting and analysing actors mental models contribute explaining how this process occur.

Faced with the taboo surrounding fire, we chose to apply the Q methodology to elicit farmers' mental models and to analyse whether or not collective action is perceived as a way to mitigate fire risk. Current fire control policies do not address the fire control dilemma; revealing mental models through Q methodology helped thinking about which policy orientation could favor a surge in collective action, and overcome the problem of lack of appropriation of fire control policies by the farmers. SMMs identified with the Q-test revealed substantial heterogeneity of views about fire use, fire risk, and norms about fire prevention and control, but consistent beliefs that fire control is essential. This suggests that clear control norms have not yet emerged and that there are competing logics: the fire control problem clearly has many configurations, and behaviours follow different patterns.

Our results suggest that a high perceived risk of fire and a low risk involvement limits collective action for fire control. Reducing risk perception may be an

effective way to achieve collective action.

Perceptions of risk depend on landscape features and the technical capacities to control fires, perceptions of coordination within and between neighborhoods, and external enforcement. While current government intervention concentrated only on the first issue, an effective policy aimed at encouraging engagement in fire control cannot ignore any of these three aspects. An institutional solution that reduces perceived fire risk and establishes clear rules for fire control could support trust building and favor collective action within and among neighborhoods. We thus believe there is an important avenue to explore how public policies can better encourage and support local collective action dynamics for fire control. On the other side a shift away from slash and burn is not always seen by farmers as a solution, and its acceptance cannot be taken for granted.

Chapter 6

Conclusions

In this section we briefly summarize the problem we focused upon, we synthesize the key challenges and key findings of the study. Finally we highlight some policy implications and the need for further research.

6.1. Synthesis of the problem

While deforestation has rapidly slowed down in the Brazilian Amazon, hotspots are increasing also in areas of reduced deforestation, indicating that accidental fires are probably increasing (Aragão and Shimabukuro, 2010).

Fire use is an effective technique largely used to clear land for annual crops and to open and regenerate pastures. However fires for agricultural purpose generate a multiplicity of ignition sources that may lead to large accidental fires, with high damages to ecosystem services (including carbon stocks) and to assets and infrastructures on the properties.

Since many externalities arise in fire management we argue that lack of fire control is essentially driven by a collective action failure.

Studying collective action for fire control is challenging because, due to the disruptive effects of fires, fire accidents have become a taboo issue. Farmers are likely to over report fire control and cooperation is rarely observable. Moreover a clear methodological and theoretical framework to study collective action has not yet been established.

We adopted a mixed method triangulation approach combining in depth semi-structured interviews and the Q methodology to study farmers' mental models, with an econometric analysis of the determinants of fire control.

6.2. Key findings across different methods and different levels

We found that three main levels are highly concerned in the choice to control fire: the neighborhood, the community and the municipality.

6.2.1. How do neighbors affect fire management choices?

In section 4.2.2 we modeled the interdependency that originates from fire management. We showed that multiple equilibria may exist, and that although farmers may prefer equilibria with high level of labor devoted to fire control, they may get stuck in low level equilibria with high fire risk and low investments in fire control measures. Q methodology highlights that this is likely to happen when most of fire risk is exogenous to the neighborhood, reducing risk involvement.

In section 4.2.4 we highlighted some of the factors that affect the optimal decision to allocate labor to fire prevention measures at the household level. Estimates in Tables 4.3 and 4.4 show how neighbors trust is an important predictor of the decision to engage in fire control, and especially of the amount of labor allocated to firebreaks clearing and the number of fire control measures implemented.

This finding confirms the observation reported in Chapter 3 that the neighborhood is the natural dimension in which decisions related to fire control are made. neighbors indeed are likely to affect fire risk in a highly significant way: we observed several forms of agreement on rules and even a case of Coasean bargain to improve fire control in a neighboring property.

6.2.2. How do the community affect fire management choices?

Not only neighbors, but also the community plays a key role. When landscape is highly flammable, community institutions may provide rules to reduce fire risk, increasing the benefits of investing in fire control measures. Even more important, communities play a crucial role in determining perceptions about fire control and whether farmers feels themselves or not responsible for mitigating fire risk.

Communities are important institutions favoring the reproduction of social capital, creating occasions of face-to-face communication and improving leadership. All those functions are key in a context in which farms are spread over a large area as are farms in the Brazilian Amazon. Within the community we observed several reciprocity practices in production and consumption, which are key in

trust building. Only during religious rites and association activities farmers have the opportunity to talk in front of most of the members of the community, discuss issues and sanction deviant behaviours. Estimates results show that participation in church activities or in associations has a positive and significant effect on implementing four fire control measures and on the time allocated to firebreaks clearing.

Community provides also many linkages with the urban world and the governmental institutions. Indeed local associations intermediate all forms of governmental programs and subsidies.

As shown in Chapter 3 and 4, increasing fire risk may lead to a low level equilibrium in which farmers cope with risk through planting non fire sensitive crops instead of investing in mitigating fire risk. This is a problem for those farmers willing to undertake a transition out of fire use since the investments risk increases.

Although community institutions provide useful coordination mechanisms for fire control and fire fighting many farmers express concern in interviews for the degradation of those institutions, in particular with respect to the role of associations that are becoming outpost of governmental bureaucracy. Many community leaders interpret their role as lobbyist in front of governmental agencies and neglect their role within the community.

Few farmers reported clear perceptions of rules in fire management within the community. Most of farmers underline monitoring and sanctioning difficulties, sanctioner's loss of legitimacy and the absence of mechanisms to manage fire conflicts and getting compensations from fire damages. In many of the communities visited in Paragominas fires were actually a taboo issue.

6.2.3. How do local and municipal policies affect fire management choices?

Attending a fire control training shows little or no correlation with the actual adoption of fire control measures and the intensity of fire control (Tables 4.3 and 4.4). Farmers are sometimes unsatisfied from training courses, the technique proposed and the style of controls (Chapter 3). However, both in Q methodology and semi-structured interviews, most of farmers prioritize an external intervention establishing rules for fire control and sanctioning deviant behaviors. Why is there such a contrast between the way government has always oriented fire trainings and the farmers demand for it?

Literature and fire prevention campaigns have always stressed the need for

new techniques and for education on ‘good’ fire management practices (Costa, 2004). We argue that farmers probably know the ‘good’ technique, but they have insufficient incentives to implement it if other farmers don’t do the same. It is a trust building issue and coordination failure problem. For example in Ipixuna the solution was a fire prevention program including some training as well as some sanctions and extensive use of conflict management. Moreover the program reduced the cost of compliance by making possible to get the fire license at the municipal Environmental Secretariat instead than in Belem, the far away capital of the Parà State.

Interviews with farmers show that the Ipixuna’s program reduced the perception that fire is an exogenous risk leading to a deeper risk involvement and lower fire risk expectations. The Q methodology application showed that Ipixuna farmers support the view that a shared intervention (i.e. state and community) is key to an effective fire control.

6.3. Policy implications and future research

Municipal governments in the Amazon should care about controlling fire risk not only for environmental and public health reasons, but for economic reasons, that is unfold the option of investing beyond non fire sensitive crops, providing farmers with the opportunity of a fire-free agriculture. This may reduce poverty among smallholders, and reduce dependence from external subsidies that have insignificant and sometimes negative effects on the decision to control fire and ultimately on environmental and economic sustainability.

Up to now policies aiming to limit fire incidence have ‘individualized’ the fire issue. More effective policies must internalize the collective dimension and the interdependency issue linked to fire control and take into account farmers’ mental models in order to improve collective action likelihood locally. For this purpose policy maker should adopt provisions for trust building and reduce the cost of compliance.

Trust building may takes place facilitating monitoring and sanctioning activity. Institutions must make farmers responsible for controlling fire, creating a shared mental model favorable to collective action. Sanctioners’ legitimacy must improve through institutions providing compensation mechanisms and increasing reporting and grievance redressal opportunities.

In order to reduce the costs of fire control and compliance to the law, local government must provide information and adequate resources in degraded area

with low forest cover. As other works already suggested (Carmenta 2013; Bronzizio and Moran, 2008), when fire risk increase (i.e. during drought and extreme climatic events), government must increase monitoring and information effort.

In the end local government must avoid drastic regulation such as Paragominas' law forbidding fire use. This increase the policy-practice gap and reduce farmers' compliance by crowding out motivation to control fire. Vice-versa a supporting regulation such as a correct implementation of the fire licensing system would make farmers responsible for controlling fire and increase the likelihood of collective action. In pursuing this it would be good to make the license release as close as possible to the farmers. Local government may invest in special fire officers delegated of releasing fire licenses and receiving complaints from farmers suffering damages. These officers may also supervise and eventually provide consultancy on fire use. Moreover in case of accidents they may implement conflict management techniques or report to the authorities such as the local police or IBAMA (Brazilian Environmental Agency). Fire officers must be operating during the whole fire season and can be located in each rural school or rural health unit. This intervention is likely to be more effective than mere training of farmers: increasing governmental and peer pressure for cooperation, improving the likelihood of collective action for fire control.

New avenues for future research include a cost benefit and political economy analysis of fire control policies. Future investigations need to assess the effective benefits of fire mitigation policies, whether local government are effectively interested in reducing fires and which is the optimal scale for policy implementation. Fruitful linkages may emerge with policies and programs oriented to improve production capacity within the boundaries of forest conservation. On the other hand an evaluation of costs and benefits of fire control is particularly challenging since few data exists about the area and type of landscape burnt, and few studies have proven able to link remote sensing data (hotspots and scars) with survey data. Moreover there is no study measuring the effectiveness of current fire control investments yet.

Future investigation may also compare the effects of policies for forest conservation based on trust building and collective action, and those based on Payment for Environmental Services (PES). Recent research and policies for forest conservation concentrated on PES as a tool to influence land use decisions. However fires are considered as contextual issues and a threat for the REDD+ scheme¹ rather than

¹ Reducing Emissions from Deforestation and Forest Degradation plus Conservation: <http://www.un-redd.org/> .

normal issue to deal with in forest conservation. Future research may explore under which conditions PES and policies for collective action may establish fruitful complementarities.

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Appendix A

Semi-structured interviews canvas

1. How did you get here? Can you tell me the history of the community? What are the main crops here? How are you organized to sell production? Are there many fire accidents in the region? Do you know people experimenting tractor use or other techniques alternative to fire? What do you think about alternative techniques to fire use?
2. What do you produce? Do you have infrastructures on your property? How do you sell your production? Do you have other income sources?
3. How was this place at your arrival? Did you always produced the same things? Have you ever changed? Why?
4. Do you practice slash and burn? How do you burn? Are you usually satisfied with burn?
5. Which prevention measures do you implement?
6. Do you also implement defence measures?
7. Do you remember the years in which the biggest fire occurred? Did you experienced damages to your property? May you list the damages you experienced? Do you think today there is the same fire risk? It gets worst or ameliorates?
8. Have you ever experienced fire accidents with your neighbors? How is it going with them? What happened? How are you organized to face fires?
9. What do the other members of the community did during the accidents?
10. May you describe the community, the association and the other organizations in the community? Are there special agreements regarding production or fire use in the community?
11. Have you already tried to set up rules for fire use with your neighbors?
12. Have you already experienced fire trainings in the community? What do

you think about? What to you think about what they say on television and on radio about fire use and fires?

13. Do you think there is need for more rules? What do you think about government policies and laws about fire use and control? Which do you think is the role of the community and which the one of public bodies in preventing fires?

14. If there was no more fire risk would you change your production system? Why? Do you think you would yield more money?

15. What do you think about the future of the community?

Appendix B

List of variables used in the models

In order of citation

γ	internal endogenous risk
ψ	external exogenous fire risk
ρ	external endogenous fire risk
ϕ	likelihood of collective action
\mathbf{Z}	vector of exogenous variables affecting collective action
p	fire risk
L_a	productive labor
L_P	the amount of labor allocated to fire production
Y	income
δ	losses
U	utility
Q_A	amount of type A crop
Q_B	amount of type B crop
Q_A	price of type A crop
Q_B	price of type B crop
K_A	production cost of A crop
K_B	production costs of B crop
U^F	utility in case of fire event
U^0	utility in case of non fire event
\mathbf{X}	vector of non agricultural goods
N	amount consumed of non timber forest products
$\mathbf{\Omega}$	vector of household features
l	leisure

T	total time endowment
L_N	labor allocated to the production of NTFPs
L_A	labor allocated to the production of A crops
L_B	labor allocated to the production of B crops
S_A	area allocated to the production of A crops
S_B	area allocated to the production of B crops
S_F	area of forest
S	total land endowment
I	exogenous income
α	protective effect of fire prevention measures
K	capital
W_h	wage rate of hired labor
\mathbf{P}_x	vector of prices of non agricultural goods
P	relative price (P_A numeraire)

Appendix C

Estimates results

Additional summary statistics

This section report summary statistics for dataset corresponding to each model.

Table C.1: Summary statistics: Firebreaks (0/1) and Firebreaks (Days)

Variable	Mean	Std. Dev.	Min.	Max.
firebreaks_01	0.818	0.387	0	1
firebreaks_days	4.527	5.343	0	30
manioc_flour_price	1.159	0.336	0.541	1.601
pepper_price	3.228	0.406	2.747	4.194
gov_transfer	0.723	0.432	0	1
church	0.662	0.459	0	1
n_association	1.055	0.811	0	3
neighbors_trust	2.797	0.46	1	3
neighbors_help	0.064	0.245	0	1
training	0.218	0.415	0	1
n_children	1.518	1.89	0	10
n_men	1.545	1.29	0	6
a_pri_forest	15.991	29.428	0	200
a_sec_forest	19.642	21.916	0	119.13
a_pasture	6.63	13.675	0	95.600
a_annual	1.947	1.833	0	10
a_perennial	0.358	0.841	0	5
N		110		

Table C.2: Summary statistics: Backfire

Variable	Mean	Std. Dev.	Min.	Max.
backfire	0.621	0.487	0	1
manioc_flour_price	1.192	0.331	0.541	1.601
pepper_price	3.232	0.423	2.623	4.206
church	0.656	0.46	0	1
n_association	1.021	0.782	0	3
neighbors_trust	2.801	0.443	1	3
neighbors_help	0.064	0.246	0	1
training	0.207	0.407	0	1
education	0.079	0.27	0	1
n_children	1.464	1.781	0	10
n_men	1.493	1.267	0	6
a_pri_forest	15.195	28.372	0	200
a_sec_forest	18.601	20.776	0	119.13
a_pasture	5.488	12.217	0	95.600
a_annual	1.815	1.746	0	10
a_perennial	0.465	1.348	0	12.5
N		140		

Table C.3: Summary statistics: Alert neighbors

Variable	Mean	Std. Dev.	Min.	Max.
alert_neighbors	0.818	0.388	0	1
manioc_flour_price	1.183	0.329	0.541	1.601
pepper_price	3.237	0.425	2.623	4.206
gov_transfer	0.745	0.417	0	1
church	0.645	0.465	0	1
n_association	1.022	0.771	0	3
neighbors_trust	2.797	0.447	1	3
training	0.212	0.41	0	1
education	0.073	0.261	0	1
n_children	1.496	1.799	0	10
n_men	1.496	1.273	0	6
a_pri_forest	16.002	28.846	0	200
a_sec_forest	18.944	20.862	0	119.13
a_pasture	5.878	12.585	0	95.600
a_annual	1.814	1.744	0	10
a_perennial	0.462	1.357	0	12.5
N		137		

Table C.4: Summary statistics: Late hours

Variable	Mean	Std. Dev.	Min.	Max.	N
late_hours	0.099	0.3	0	1	181
manioc_flour_price	1.195	0.328	0.541	1.601	169
pepper_price	3.193	0.395	2.623	4.206	181
gov_transfer	0.74	0.424	0	1	181
church	0.641	0.462	0	1	181
neighbors_trust	2.813	0.425	1	3	181
neighbors_help	0.063	0.243	0	1	176
training	0.193	0.396	0	1	181
education	0.077	0.268	0	1	181
n_children	1.503	1.928	0	14	181
n_men	1.448	1.271	0	6	181
a_pri_forest	13.472	26.126	0	200	181
a_sec_forest	17.556	19.331	0	119.13	181
a_pasture	5.782	12.032	0	95.600	181
a_annual	1.652	1.694	0	10	181
a_perennial	0.414	1.211	0	12.5	181

Table C.5: Summary statistics: Number of fire control measures implemented

Variable	Mean	Std. Dev.	Min.	Max.
n_fcm	2.815	1.232	0	5
manioc_flour_price	1.157	0.339	0.541	1.601
pepper_price	3.221	0.402	2.747	4.194
gov_transfer	0.722	0.435	0	1
church	0.674	0.454	0	1
n_association	1.056	0.818	0	3
neighbors_trust	2.802	0.458	1	3
neighbors_help	0.065	0.247	0	1
training	0.222	0.418	0	1
education	0.074	0.263	0	1
n_children	1.463	1.831	0	10
n_men	1.537	1.3	0	6
a_pri_forest	15.704	29.31	0	200
a_sec_forest	19.285	21.774	0	119.13
a_pasture	6.418	13.486	0	95.600
a_annual	1.944	1.849	0	10
a_perennial	0.362	0.848	0	5
N		108		

Estimates details

This section reports estimates of all the models presented in Tables 4.3 and 4.4. We add also estimates with `n_men` in log form of burning after the rain (Table C.13) and of the number of daywork devoted to build fire control measures (Table C.14). Finally, in Table C.15 we report the average marginal effects for all Probit models. All standard errors are robust to heteroskedasticity.

Table C.6: Probit estimation results : Firebreaks

Variable	Coefficient	(Std. Err.)
manioc_flour_price	0.884	(0.588)
pepper_price	1.123*	(0.516)
gov_transfer	-0.039	(0.329)
church	0.308	(0.364)
n_association	0.393 [†]	(0.236)
neighbors_trust	1.094**	(0.347)
neighbors_help	0.114	(0.691)
training	-0.095	(0.479)
n_children	-0.064	(0.081)
n_men	0.058	(0.131)
a_pri_forest	-0.004	(0.007)
a_sec_forest	0.019*	(0.009)
a_pasture	0.000	(0.018)
a_annual	0.014	(0.099)
a_perennial	0.377 [†]	(0.220)
Intercept	-7.561**	(1.983)
N	110	
Log-likelihood	-38.15	
$\chi^2_{(15)}$	34.417	
Significance levels : † : 10% * : 5% ** : 1%		

Table C.7: Probit estimation results : Backfire

Variable	Coefficient	(Std. Err.)
manioc_flour_price	1.372**	(0.471)
pepper_price	-0.259	(0.321)
church	0.599*	(0.275)
n_association	0.187	(0.178)
neighbors_trust	0.505 [†]	(0.272)
neighbors_help	1.258*	(0.579)
training	0.029	(0.304)
education	0.048	(0.465)
n_children	-0.020	(0.070)
n_men	-0.140	(0.108)
a_pri_forest	-0.008	(0.005)
a_sec_forest	0.030**	(0.009)
a_pasture	0.033*	(0.015)
a_annual	-0.070	(0.075)
a_perennial	0.068	(0.102)
Intercept	-2.738*	(1.361)
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N	140	
Log-likelihood	-75.621	
$\chi^2_{(15)}$	32.592	
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Significance levels :	† : 10%	* : 5% ** : 1%

Table C.8: Probit estimation results: Alert neighbors

Variable	Coefficient	(Std. Err.)
manioc_flour_price	1.259*	(0.571)
pepper_price	1.121*	(0.438)
gov_transfer	-0.464	(0.333)
church	0.689*	(0.335)
n_association	-0.045	(0.188)
neighbors_trust	0.589	(0.360)
training	0.542	(0.410)
education	-0.206	(0.539)
n_children	-0.061	(0.085)
n_men	0.180	(0.133)
a_pri_forest	-0.004	(0.006)
a_sec_forest	-0.005	(0.007)
a_pasture	-0.027*	(0.012)
a_annual	0.192*	(0.093)
a_perennial	0.032	(0.090)
Intercept	-5.908**	(2.004)
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N	137	
Log-likelihood	-45.396	
$\chi^2_{(15)}$	38.467	
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Significance levels :	† : 10%	* : 5% ** : 1%

Table C.9: Probit estimation results: After rain

Variable	Coefficient	(Std. Err.)
manioc_flour_price	1.010*	(0.469)
pepper_price	0.798*	(0.326)
gov_transfer	0.523 [†]	(0.295)
church	0.067	(0.285)
n_association	0.306 [†]	(0.175)
neighbors_trust	-0.094	(0.265)
neighbors_help	1.149	(0.738)
training	0.483	(0.322)
education	0.207	(0.500)
n_children	-0.007	(0.064)
n_men	0.066	(0.101)
a_pri_forest	0.005	(0.005)
a_sec_forest	0.000	(0.008)
a_pasture	-0.013	(0.012)
a_annual	-0.015	(0.071)
a_perennial	0.130	(0.079)
Intercept	-4.447**	(1.304)
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N	134	
Log-likelihood	-70.935	
$\chi^2_{(16)}$	39.651	
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Significance levels :	† : 10%	* : 5% ** : 1%

Table C.10: Probit estimation results: Late hours

Variable	Coefficient	(Std. Err.)
manioc_flour_price	2.049	(1.625)
pepper_price	-5.795*	(2.559)
gov_transfer	1.420	(0.888)
church	0.012	(0.845)
neighbors_trust	2.772 [†]	(1.474)
neighbors_help	0.535	(0.706)
training	1.996**	(0.617)
education	1.370	(0.880)
n_children	-0.741**	(0.240)
n_men	-0.168	(0.146)
a_pri_forest	-0.274**	(0.096)
a_sec_forest	-0.008	(0.010)
a_pasture	0.127**	(0.040)
a_annual	-1.086**	(0.398)
a_perennial	1.077**	(0.351)
Intercept	4.043	(3.904)
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N	164	
Log-likelihood	-9.875	
$\chi^2_{(15)}$	43.876	
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Significance levels : † : 10% * : 5% ** : 1%		

Table C.11: Poisson estimation results: Firebreaks days

Variable	Coefficient	(Std. Err.)
manioc_flour_price	-0.006	(0.447)
pepper_price	0.107	(0.297)
gov_transfer	0.133	(0.298)
church	0.358 [†]	(0.198)
n_association	0.143 [†]	(0.085)
neighbors_trust	0.816**	(0.250)
neighbors_help	0.212	(0.290)
training	0.178	(0.307)
education	-0.204	(0.398)
n_children	-0.153**	(0.050)
n_men	0.063	(0.089)
a_pri_forest	-0.002	(0.002)
a_sec_forest	0.002	(0.004)
a_pasture	0.007	(0.007)
a_annual	0.195**	(0.041)
a_perennial	-0.015	(0.095)
Intercept	-2.110 [†]	(1.116)
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N	110	
Log-likelihood	-328.381	
$\chi^2_{(16)}$	72.092	
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Significance levels :	† : 10%	* : 5% ** : 1%

Table C.12: Poisson estimation results: n_fcm

Variable	Coefficient	(Std. Err.)
manioc_flour_price	0.585**	(0.170)
pepper_price	0.162†	(0.091)
gov_transfer	0.022	(0.090)
church	0.135	(0.091)
n_association	0.059	(0.043)
neighbors_trust	0.375**	(0.127)
neighbors_help	0.315*	(0.131)
training	0.114	(0.075)
education	0.089	(0.135)
n_children	-0.032	(0.029)
n_men	0.020	(0.031)
a_pri_forest	0.000	(0.001)
a_sec_forest	0.003	(0.002)
a_pasture	0.002	(0.003)
a_annual	0.017	(0.020)
a_perennial	0.022	(0.042)
Intercept	-1.588**	(0.493)
N	108	
Log-likelihood	-174.567	
$\chi^2_{(16)}$	52.246	
Significance levels : † : 10% * : 5% ** : 1%		

Table C.13: Probit estimation results: After rain (with diminishing return on labor)

Variable	Coefficient	(Std. Err.)
manioc_flour_price	0.866	(0.560)
pepper_price	0.949**	(0.349)
gov_transfer	0.463	(0.332)
church	0.195	(0.334)
n_association	0.149	(0.206)
neighbors_trust	-0.057	(0.273)
neighbors_help	1.127	(0.722)
training	0.194	(0.349)
education	-0.029	(0.545)
n_children	0.051	(0.067)
log_n_men	0.664*	(0.277)
a_pri_forest	0.003	(0.006)
a_sec_forest	-0.003	(0.007)
a_pasture	-0.005	(0.014)
a_annual	-0.061	(0.073)
a_perennial	0.168	(0.142)
Intercept	-4.994**	(1.395)
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N	106	
Log-likelihood	-56.839	
$\chi^2_{(16)}$	34.386	
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Significance levels :	† : 10%	* : 5% ** : 1%

Table C.14: Poisson estimation results: Firebreaks days (with diminishing return on labor)

Variable	Coefficient	(Std. Err.)
manioc_flour_price	0.123	(0.446)
pepper_price	0.345	(0.258)
gov_transfer	0.104	(0.341)
church	0.295	(0.182)
n_association	-0.080	(0.109)
neighbors_trust	0.729**	(0.216)
neighbors_help	0.670**	(0.226)
training	-0.045	(0.208)
education	-0.154	(0.366)
n_children	-0.082 [†]	(0.044)
log_n_men	0.415*	(0.174)
a_pri_forest	-0.005*	(0.002)
a_sec_forest	0.001	(0.004)
a_pasture	0.010	(0.007)
a_annual	0.123**	(0.040)
a_perennial	0.185*	(0.089)
Intercept	-2.629*	(1.126)

N	89
Log-likelihood	-230.224
$\chi^2_{(16)}$	70.803

Significance levels :	† : 10%	* : 5%	** : 1%
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Table C.15: Summary Table: Average marginal effects for Probit models

	firebreaks (0/1)	backfire	alert_neighbors	after_rain	late_time
manioc_flour_price	0.884	1.372***	1.260**	1.010**	2.049
pepper_price	1.122**	-0.259	1.121**	0.798**	-5.794**
gov_transfer	-0.039		-0.464	0.523*	1.420
church	0.308	0.560**	0.689**	0.067	0.012
n_association	0.393*	0.187	-0.045	0.307*	
neighbors_trust	1.094***	0.505*	0.589	-0.094	2.772*
neighbors_help	0.114	1.259**		1.149	0.535
training	-0.095	0.029	0.542	0.483	1.996***
education		0.048	-0.206	0.207	1.370
n_children	-0.064	-0.020	-0.061	-0.007	-0.741***
n_men	0.058	-0.140	0.180	0.066	-0.168
a_pri_forest	-0.004	-0.008	-0.004	0.005	-0.274***
a_sec_forest	0.018**	.030***	-0.005	0.000	-0.008
a_pasture	0.000	.0326**	-0.027**	-0.013	0.127***
a_annual	0.014	-0.070	0.192**	-0.015	-1.086***
a_perennial	0.377*	0.068	0.032	0.130	1.077***
Constant	-7.560***	-2.737**	-5.909***	-4.447***	4.043
Pseudo R^2	0.269	0.186	0.303	0.230	0.755
N	110	140	137	134	164
chi2	34.417	32.592	38.467	39.651	43.876

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Appendix D

Technical notes on Q methodology

The whole routine used to analyse data is made up of the following steps:

- 1 Organize data in a SxN matrix (in our case R=17, N=56), with statements in raw and Q sorts by column.
- 2 Perform factor analysis on Q sorts (we used the Stata command factor).
- 3 Perform factor rotation (we used Stata command rotate which perform a varimax rotation).
- 4 Calculate a sort significant threshold and define significant sorts.
- 5 Select an adequate number of factors.
- 6 Assess factor reliance.
- 7 Obtain normalized factor scores (Table 5.3).
- 8 Asses most distinguished statements.
- 9 Cross the individuated factors with relevant features of the individuals whose Q sort belong to the individuated factor (Table 5.4).

Steps 1 to 3 and 5 are straight or discussed in Chapter 5. Step 9 is described in the footnote to Table 5.4. Here we discuss steps 4, 6, 7 and 8.

Calculate a sort significant threshold and define significant sorts

Calculating sort significance is important to understand which sorts are significant variants and which are not. Sort whose factor loading surpassed a threshold indicating that sort significance was greater or equal to 99% on that factor were considered significant on that factor. Q sort that is not significant on any of the

selected factor is dropped from the analysis. This means that further discourses exist, but in our sample there is no sufficient variance to aggregate them on a single factor.

According to Brown (1980) the threshold to decide factor significance can be calculated with the formula:

$$T = \frac{z}{\sqrt{N}}$$

where z is the value of the standard normal PDF use to set significance, in our case is 2,58; and N is the number of sorts included in the sample, in our case 56. So we considered significant only those sort whose factor loading where positive and exceeded $T=0,345$.

Assess factor reliance

How much each sort really reflect the discourse of the person whose sort load on that factor? Brown (1980) suggests that the reliability of a person with himself is around 80%. Repeating the same ranking exercise several times individual will change opinion once over five statements.

Then the reliability of a factor with itself can be estimated as:

$$r_{xx} = \frac{0.80p}{1 + (p - 1)0.80}$$

where p is the number of person whose sorts load significantly on that factors or that in Brown's words "define the factor". The more persons will define that factor the more the factor is reliable.

Obtain normalized factor scores

Normalized factors score are obtained as a weighted average of the sort significantly loading on a factor. The weight is $w = \frac{f}{(1-f^2)}$. Scores are then normalized subtracting score average and score means for each factor. This allow to evidence most contrasting statements.

Assess most distinguished statements

In order to assess if two sort are significantly different we must build a test. We proceed by computing standard errors of factor score: $SE_{fs} = s_x(1 - r_{xx})$ where s_x is the standard error of the forced distribution. Since we standardized factor scores we used $s_x = 1$.

Then we compute the standard error of the difference between two factor scores:

$$SED_{x-y} = \sqrt{SE_x^2 - SE_y^2}$$

If the difference between two scores is higher than $zSED_{x-y}$, then the two scores are significantly different at the level of significance set by setting z : $p < 0.1$ for $z = 1.65$; $p < 0.05$ for $z = 1.96$; $p < 0.01$ for $z = 2.58$.