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Abstract

Despite a fall in deforestation, frequency and severity of fires in the Brazilian Amazon are rising, causing huge carbon emissions, biodiversity losses and local economic costs. The ignition sources are anthropogenic and mostly related to the accidental spread of agricultural fires. Fire risk mitigation is a coordination problem with strategic complementarities: a farmer's benefit of mitigation depends on complementary action of other farmers. We experimentally assess *ex-ante* the impact of two different policies under varying exogenous drought risk scenarios. Command and control is more effective than payments for environmental services in promoting coordination, possibly because of participants' risk aversion (to the fine) and a local demand for justice and law enforcement. We also find evidence of a human-mediated self-reinforcing loop of drought and fires: droughts increase the exogenous component of fire risk, giving farmers less incentives to mitigate fire risk coming from their own farms.

Keywords: Brazilian Amazon, forest fires, climate change, framed field experiment, coordination games

JEL codes: C93, Q23, Q54

1 Introduction

Tropical forests are burning (Cochrane, 2003; Coe et al., 2013). The South and Eastern Amazon, despite an 80% fall in deforestation since 2004, has experienced a clear upward trend in the number and extension of forest fires for the last decades (Alencar et al., 2015; Aragao and Shimabukuro, 2010; Malhi et al., 2008; Morton et al., 2013). Fire plays a key role in Amazonian smallholders' livelihoods and it is widely used for land clearing, weed control and fertilization (Börner et al., 2007; Carmenta et al., 2013). Each time fire is used for agriculture or pasture maintenance, however, it represents a potential ignition source for forest fires (Cano-Crespo et al., 2015; Diaz et al., 2002). Such accidental fires double biodiversity losses from deforestation (Barlow et al., 2016), reducing the forest environmental services and the natural resource base of local communities (Barlow et al., 2012). Fires reduce up to 40% of the potential carbon stock of standing forest and generate CO_2 emission (Barlow et al., 2012; Berenguer et al., 2014). The 2010 fires alone generated 510 ± 120 $MtCO_2$ emissions (Anderson et al., 2015). Fires can destroy agricultural produce and infrastructure, and make local populations suffer from health problems (Cochrane, 2003; de Mendonça et al., 2004; Nepstad et al., 2001; Nepstad et al., 1999; Smith et al., 2014).

Understanding fire use and control in private properties is key for the Amazon conservation. About 45% of the Amazon forest is under a special protection regime, but most fires occur outside them (Nelson and Chomitz, 2011; Nepstad et al., 2006; Soares-Filho et al., 2010). Private properties normally have abundant flammable vegetation (Alencar et al., 2015; Cochrane, 2003) with potentially high conservation value (Karthik et al., 2009; Parry et al., 2007) but difficult to govern (Vieira et al., 2014). Tasker and Arima (2016) show that deforestation policies probably reduced the number of agricultural fires, but did not reduce the area burnt due to the high frequency of accidental forest fires. Supplementary policies to target fires are needed (Barlow et al., 2012).

This paper reports on a framed field experiment (FFE) on fire use on private lands in the Brazilian Amazon. Similarly to Morello et al. (2017) but with a different method (FFE vs. agent-based model), we provide an *ex-ante* assessment of two key fire-preventing policies: Command and Control (CAC) and Payment for Environmental Services (PES). These two experimental treatments emulate highly relevant policies whose impact is mostly unknown (Morello et al., 2017).

CAC has been a cornerstone in the Brazilian efforts to end deforestation (Börner et al., 2015). Yet, there is little law enforcement concerning fires. The Brazilian Forest Code (Chap. IX, law 12651/2012) is the main legislation on fire use and control. Each state is responsible for the enforcement of the Forest Code on private properties, and its implementation varies. Mato Grosso, Acre, Roraima and Amapá has special fire management committees, while Pará has limited infrastructure to enforce the law. Municipalities could play an important role in fire prevention and suppression, as institutions closer to the forest areas and concerned populations.

PES represents the remuneration schemes for forest conservation and another key ingredient of the government's strategy to end deforestation, PPCDAM[1]. PES is also promoted by the international REDD+ initiative under the UNFCCC framework[2], and financed in Brazil through the Amazon Fund (Coudel et al., 2015; May, 2009). PES were pioneered in Brazil in 2003, and were recently relaunched with the *Bolsa verde* program (2011) and the *Assentamentos Sustentaveis na Amazonia* project (2015). PES has also been recognized as a forest conservation tool in the revised Forest Code of 2012 (Coudel et al., 2015), and has become integrated into NGO operations in the Amazon (e.g., Simonet et al. (2015)). To effectively reduce forest losses, REDD+ initiatives should aim to reduce fire risk in the Amazon, but so far few specific institutional measures are in place (Barlow et al., 2012). Several challenges remains for measuring, reporting and verification (MRV) mainly because of unclear responsibilities and liabilities associated with fire events (Barlow et al., 2012).[3]

We examine these policies under a stable climate and a climate change scenario. Climate change is expected to increase drought risk in the Amazon (Dai, 2013; Malhi et al., 2008), which in turn increases fire occurrence and extension (Alencar et al., 2006; Brando et al., 2014; Brando et al., 2016; Davidson et al., 2012; Nepstad et al., 2004; Schwartz et al., 2015).

We design the experiment as a coordination game with strategic complementarities; the benefit of investing in risk mitigation depends on neighbors' complementary action (Shafran, 2008), generating a dilemma between a sure return and uncertain social cooperation outcome. The aggregate of local choices gives the neighborhood fire risk. The design also includes drought-induced fire risk. Nepstad et al. (2001) and Nepstad et al. (2008) hypothesize that neighbors' use of uncontrolled agricultural fire and drought conditions generate an external fire risk that reduces the individual incentives for fire-free agricultural practices. This might engender a feedback loop between higher expected losses, less fire control and thus even more fires. We test experimentally whether such a drought-fire self-reinforcing loop exists. If it does, climate change will have a greater impact on fire risk than the one predicted by physical models that do not account for such a human-mediated climate effect.

Specifically, we aim to answer the following questions:

1. Is there a human-mediated, self-reinforcing loop between droughts (climate change) and fire use, as posited by Nepstad et al. (2001)?
2. Which policies are effective in reducing fire risk by promoting fire control and fire-free practices, and how do they interact with drought risk?

Our results shows that farmers react to drought risk and droughts occurrence by increasing uncontrolled fire use. This suggests that the climate change impact is partially human-mediated, but policies have the potential to break this loop, in particular when policies are aligned with local norms. The enforcement of the Forest Code appears to be the most effective policy in reducing uncontrolled fires because it addresses directly the source of the externality and farmers' beliefs about fire risk. Further, we find that farmers are motivated by

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[1] http://www.mma.gov.br/images/arquivo/80120/PPCDAm/_FINAL_PPCDAM.PDF last visit: 05/04/17 16:30.
[2] http://redd.unfccc.int last visit 05/05/16 16:30.
[3] Morello et al., (2017) report further details on CAC and PES policies against forest fires in the Brazilian Amazon.

expected payoffs, which in part are determined by their beliefs, lending support to our assurance game framing. Finally, a strong fire control norm and perceived technological constraints play an important role in their choices, suggesting behavioral validity.

Section 2 discusses the economics of forest fires and related policies. Section 3 outlines the experimental design, treatments and theoretical predictions. Section 4 reports on the study site and sampling, section 5 on the results, while section 6 discusses the findings and section 7 concludes.

2 The brief economics of fires and fire policies

2.1 Background

Lacking natural ignitions, fires in the rainforests appear due to a combination of droughts and land use practices by local populations (Cano-Crespo et al., 2015; Nepstad et al., 2001; Nepstad et al., 2008; Schwartz et al., 2015; Soares-Filho et al., 2012). The underlying socioeconomic drivers of fires have only to a limited degree been explored (Carmenta et al., 2011). Research has concentrated on smallholders, possibly because large-holders are already undergoing a transition out of fire use, while smallholders appear to have less incentives and/or capacity to abandon fire-intensive agricultural practices in the short and medium term.

Controlled fire is a cheap "voluntary worker", substituting for capital and labor in land preparation, pest control and soil mineralization in pastures and cropland (Nepstad et al. 1999). Many obstacles to fire-free alternatives are well documented and relate to poor market access, high costs and unavailability of labor and capital, and network externalities associated with local knowledge (Harwood, 1996; Hoch et al., 2009; Hoch et al., 2012; Pokorny et al., 2012).

The population responsible for igniting accidental fires are also the one suffering its most direct damages (Nepstad et al., 1999; Schroth et al., 2003). They should therefore also be the agents most concerned about fire prevention. This apparent paradox can be portrayed as a coordination problem. The farmer's benefits of investing in controlled fire consists of the avoided damage of his own plot burning from his own fire (Bowman et al., 2008). The benefits depend on how he values the fire sensitive assets, including other crops, infrastructure and the forest itself (Nepstad et al., 2001). Bowman et al. (2008) show that farmers' investment in preventive firebreaks indeed depends on the value of the flammable assets at stake on their land.

Fires may also spill into the property from neighboring fields and forests, irrespectively of the preventive measures undertaken by the farmer himself[4]. We term this risk the *neighborhood fire hazard* (NFH) because it is determined endogenously by neighbors' choices. In our sample, about 41% (N=238) of fire damages originate from fires ignited by neighbors. The private benefit of investing in preventive fire control measures therefore depends on the NFH faced by the farmer: the lower the NFH, the higher the benefit of controlling the own fire because the residual risk of asset losses is low. Since decisions are taken before the NFH is observed, it is the farmer's *belief* about the NFH level that matters. Another consequence of the fire control coordination problem is that high-yield, fire-free (but fire-sensitive)

[4] We do not consider fire protection investments; for smallholders, they would be even more technically demanding than fire control, and we never observed them in the field.

technologies might be unappealing to smallholders if the external fire risk is too high[5]. Hoch et al. (2009) estimate that the fire risk to an agroforest during its productive life ranges between 15 and 60%. Schroth et al. (2003) report that 55% of the interviewed farmers remember loosing trees because of fires, and that risk is the main limiting factor to the establishment of rubber tree plantations. de Mendonça et al. (2004) find that about 16 000 km of pasture fences and between 6 500 and 19 400 km^2 of pastures are lost annually because of fires.

The fire control problem represents a coordination game with strategic complementarities[6], exhibiting two Nash equilibria (Shafran, 2008). The uncoordinated ('bad') equilibrium involves high fire risk, high fire use and low yield, while the coordinated ('good') equilibrium entails low fire risk, low fire use and high yield. The equilibrium selection is determined, *inter alia,* by farmers' incentives and ability to coordinate with their neighbors, which again is influenced by a number of factors, as we return to.
In addition to neighborhood fires, there is a second source of fires. During drought years, fires increase in frequency and extension (Alencar et al., 2015), spreading for several kilometers due to high fuel availability. Brazilian farmers refer to these fires as *fogo de longe* (fires [coming] from afar). They are responsible for about half of the fire damages reported in our survey.

Climate change is expected to increase the frequency of droughts (Dai, 2013; Malhi et al., 2008). A higher drought risk reduces the incentives for fire-free agricultural practices and fire control because it increases the probability that costly fire prevention is a wasted effort. Moreover, increasing drought risk *per se* might also affects agents' behavior by initiating a spiral of self-fulfilling negative expectations. If drought risk is expected to increase over time, more agents may stop controlling fire, which in turn increase risk today. Anticipating future drought and changes in others' behavior might, in itself, trigger higher NFH today.

2.2 Analytical framework

Each farmer i decides on the fraction t_i of his privately endowed land to operate with fire, yielding a per-unit amount f, and the fraction $1 - t_i$ to operate with a fire free technique, yielding a per-unit amount a. The fire free technique gives a higher return ($a>f$), but has an associated cost r and the investments are exposed to fire risk. Further, farmers can choose to adopt fire control management practices on the fraction of land φ_i of t_i ($\varphi_i \leq t_i$), at a cost c. Fire risk depends on the choices of the participant, the average choices of the others, and the exogenous drought risk probability θ. The severity of the exogenous risk is given by the loss rate λ, i.e. the share of a that is lost.

[5] Alternatives to fire use are generally more productive but also more fire sensitive (Bowman et al.,2008; Hoch et al., 2012; Nepstad et al., 2001; Nepstad et al., 1999). Intuitively, any productive system needs more (fire sensitive) inputs than slash and burn agriculture. Pasture rotation involves more pasture fences, which are typically flammable (see De Mendonca et al., 2005). Perennial crops, tree harvesting and agroforestry involve sunk costs (initial investment and opportunity cost of land) and can be entirely lost in a fire. Plots of mechanized annual crop host flammable debris and are at risk during the burning period.

[6] Strategic complementarities occur when agents have incentives to coordinate on the same choice. Strategic substitutes occur when agents are better off coordinating on opposite choices. Both cases are discussed in the context of fire prevention investments by Shafran (2008).

The endogenous fire hazard, the fraction of $(1-t_i)a$ lost due to a locally initiated (endogenous) fire is determined by the choices of the farmers, given by: $\left[\frac{(\varphi_i-t_i)+\frac{\sum_{-i}(\varphi_{-i}-t_{-i})}{n-1}}{2}+1\right]^2$.

The endogenous fire hazard depends on the aggregate land operating with fire techniques and no fire control. The chosen functional form gives increasing benefits from fire control and allocation of land to alternative techniques as other neighboring farmers do the same.

The resulting payoff function is:

$$V_i(\varphi_i,\varphi_{-i},t_i,t_{-i};\ a,f,\theta,\lambda,r) = t_i f + (1-t_i)a\left\{\left[\frac{(\varphi_i-t_i)+\frac{\sum_{-i}(\varphi_{-i}-t_{-i})}{n-1}}{2}+1\right]^2-\theta\lambda\right\}-\varphi_i\, c-\ (1-t_i)r$$

Under the conditions:

$$\left\{a,f,\theta,\lambda,r,\textstyle\sum_{-i}(\varphi_{-i}-t_{-i})\ \middle|\ f<a(1-\theta_t\lambda)-r\ ;\ f>a\left[\left(\frac{\sum_{-i}\varphi_{-i}-t_{-i}}{2(n-1)}+1\right)^2-\theta\lambda\right]-r\ \right\}$$

this game has two Nash equilibria and exhibits strategic complementarities. The first condition states that allocating all land to fire free techniques is an equilibrium when fire risk is sufficiently low. The second condition implies that operating all land with fire is optimal when NFH is sufficiently high.

The CAC treatment simulates the impact of enforcing the Forest Code prohibition of uncontrolled fires. In each treatment round there is a probability v of a police control. If a participant choses $\varphi_i < t_i$ and a control takes place, he receives a fine of $(\varphi_i - t_i)z$ points.

The resulting payoff function is: $U(\varphi_i,\varphi_{-i},t_i,t_{-i};\ a,f,\theta,\lambda,r,v,z) = V_i(\varphi_i,\varphi_{-i},t_i,t_{-i}) - (\varphi_i - t_i)vz$

PES makes alternatives to fire use more attractive to farmers, as in the *Bolsa Floresta* program described in Bakkegaard and Wunder (2014). The PES treatment covers a share s of the costs associated with allocating land to fire free-techniques.

The payoff function after the payment is: $U(\varphi_i,\varphi_{-i},t_i,t_{-i};a,f,\theta,\lambda,r,s) = V_t(\varphi_i,\varphi_{-i},t_i,t_{-i}) + (1-t_i)s$

3 The experiment

3.1 Design

The experiment consists of 10 rounds. A group of 8 participants is told that they are neighboring farmers with a plot of land of equal size. In each round, each participant chooses anonymously and simultaneously among three cultivation technologies:

F $(t_i = 1, \varphi_i = 0)$: fire use without prevention measures
CF $(t_i = 1, \varphi_i = 1)$: controlled fire, fire with prevention measures
A $(t_i = 0, \varphi_i = 0)$: alternatives to slash and burn, e.g., mechanization, agroforestry or pasture rotation.[7]

[7] In reality, most farmers adopt a wider variety of t_i and φ_i combinations. This enhance food security and allows adapting to available resources. However, there would have been no gain in realism by introducing additional

We calibrate the payoff function with fire free agriculture yielding a=250, with an associated cost $r = 50$, fire-using techniques yielding f=100, with an associated control cost $c = 30$, the loss parameter $\lambda = 0.5$ and the exogenous risk $\theta \in [0, 0.6]$. The resulting payoff tables are displayed in Table 1.

Fire-intensive crops are not flammable, thus choices F and CF yield a constant payoff of 100 and 70, irrespective of drought occurrence and NFH (number of other participants choosing F). The payoff of choice A varies. When a drought occurs, the payoff is reduced. The left panel of Table 1 represents the normal situation, while the right panel gives the payoff when a drought occurs. Within each of these two scenarios, the payoff of A depends on the other participants' choices (NFH). Without fire risk, the payoff of A is twice the one of F. Although there is uncertainty about the overall return of fire-free techniques (Morello et al., 2017), to calibrate our model we relied on information collected from agronomists working in the specific region of study (Nepstad et al., 1999; Coudel, personal communication).

Table 1 Payoff table in the absence (left) or the occurrence (right) of a drought

NFH	A	F	CF
0	200	100	70
1	166	100	70
2	134	100	70
3	104	100	70
4	78	100	70
5	53	100	70
6	32	100	70
7	13	100	70

NFH	A	F	CF
0	75	100	70
1	41	100	70
2	9	100	70
3	0	100	70
4	0	100	70
5	0	100	70
6	0	100	70
7	0	100	70

After reading the instructions aloud to the participants, and before the experiment started, one trial round was played and the experimenter answered all questions raised. In each round, participants were asked to box-tick their choice of cultivation technology on a tip of paper, and to state the anticipated NFH. The task was designed such that also illiterate participants were comfortable in making the choice on their own, thus minimizing the interaction with the experimenter and possible Hawthorne effects. To minimize unwanted interactions,

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choices in the experiment: complexity would have increased significantly, without changing the salience of any solution concept. Any combination of F, CF or A is strictly dominated by A or F.

participants were sitting in a circle with the chairs turned outwards. Policy treatments were introduced by reading aloud further instructions and answering all questions.

All participants played five baseline rounds and five policy treatment rounds. No communication was permitted during the experiment. At the end of each round, the experimenter collected the paper with participants' choices, announced the frequency of each choice, the random realization of a drought or not, and the resulting payoff for each choice. Whether a drought occurred or not was determined by rolling a 10 sided dice, with the probability known to the participants.

Participants in half of the sessions played with stable drought risk while the other half faced increasing risk (Table 2). To avoid spillover effects we never repeated an experiment more than twice and a treatment more than once in the same community. We balanced the sample size across treatment groups (Table 2).

Table 2 Treatments set-up and number of sessions for each treatment

Fire policy→ Drought risk↓	CAC	PES	N
Constant	12	12	24
Increasing	12	12	24
N	24	24	48

The CAC treatment was obtained by setting the probability of a police control $c = 1/3$ and the fine to $z = 73$; PES was given by the amount of the payment, $s = 30$. Under this specification and the parameters definition, PES and CAC are theoretically equivalent and directly comparable, as we return to below.

Under the constant risk treatment, there was a 30% drought probability corresponding to $\theta = 0.3$. Under the increasing risk treatment, the probability rose from 0 to 60%, with $\theta \in [0\,;\,0.6]$ (Table 3**Error! Reference source not found.**), such that the baseline and policy treatment rounds are risk-equivalent with an average of 30% for both the stable and increasing risk treatments. This allowed testing for an increasing-risk effect on participants' choices.

Table 3 Drought risk distribution across rounds and risk treatments

	Baseline					Policy Treatment				
Rounds	1	2	3	4	5	6	7	8	9	10
Stable	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
Increasing	0%	10%	30%	50%	60%	0%	10%	30%	50%	60%

A short questionnaire was administered before and after the experiment to collect data about agricultural production, fire use and control, and sociodemographic characteristics.

The points earned in the experiment were converted into cash at the end of the session at a rate of 80 points = 1BRL. Participants were thus able to earn up to 35 BRL[8], approximately one local daily wage for unskilled labor in agriculture.

Detailed instructions are reported in the on-line material.

3.2 Theoretical predictions and hypotheses

The game exhibits two Pareto ranked Nash equilibria, F and A. CF is always strictly dominated, thus we expect to observe few CF choices. A high number of CF choices might evidence a social norm prescribing controlled fire or pro-social preferences and risk-aversion.

A rational, selfish pay-off maximizing and risk neutral agent will choose A or F depending on the expected risk of drought, and his belief about NFH (between 0 and 7). There exists a NFH belief threshold above which the expected return of A is lower than the sure return of F. Below (above) that threshold the agent is expected to choose A (F) (Table 4).

Table 4 Theoretical NFH belief threshold causing a risk neutral and selfish agent to switch from A to F

Risk	Baseline	CAC	PES
0	4	5	5
10%	3	4	4
30%	2	3	3
50%	2	3	3
60%	1	2	2

A risk averse participant has a higher belief threshold than a risk neutral one. A pro-social participant experiences a lower belief threshold as he accounts for the damage imposed on others if playing F. Rounds with high fire risk (30% - 60%) are expected to give lower frequencies of choice A and higher of choice F, because the belief threshold are lower than in low risk rounds (0 - 10%).

Because the two drought risk scenarios are equivalent on average for the risk neutral player, any difference between the two treatments in baseline rounds might be due to the effect of increasing risk *per se*. In coordination games, expectations about the other participants' action is critical for own choice (Van Huyck et al., 1990). We posit that increasing risk *per se* creates more uncertainty about other players choices compared to a stable risk level, because the payoff of choosing A diminishes over rounds. Participants might thus anticipate their opponents F choice in the next round and play F in current round, engendering a spiral of negative and self-fulfilling beliefs leading to more F choices.

In addition, when risk increases, risk-averse participants become less prone to choose A. This will work partly through reduced expected own payoffs and partly through changes in expectations of what other participants will choose, i.e., a change in the believed NFH. Climate change (i.e., increasing drought risk) might therefore trigger negative expectations that make participants even more likely to choose F instead of A, beyond the mere effect of risk level.

[8] At the end of the survey (Nov. 2015), the exchange rate was ca. 4 BRL = €1.

The chosen parameter values ensure that CAC and PES are theoretically equivalent in the sense that, for a risk neutral, selfish player, the belief thresholds are the same (Table 4). Any difference across treatments impact can be ascribed to the institutional difference between CAC and PES, or to preferences.

Our treatments may affect choices through crowding in/out of intrinsic motivations. Vollan (2008) defines CAC and PES in a Common Pool Resource game as the first being restrictive and the second being enabling (of participants choices), thus different crowding in/out effects can be expected. However, Gneezy and Rustichini (2000) and Cardenas et al. (2000) find that both payments and law enforcement might crowd out social norms when these are internalized. In our experiment, both CAC and PES are enabling of A, because F is not the only Nash equilibrium.

The equivalence of CAC and PES do not hold for non-risk neutral players: risk aversion (loving) reduces (increases) the evaluation of F payoff for any positive probability of being fined. CAC is thus expected to be more effective on risk averse players than PES.

Policy and drought risk treatments may interact. Increasing risk should raise participants' believed NFH, while policies should reduce it. The impact of policies is expected to be higher under increasing rather than stable risk. The opposite might occur if drought risk impact is stronger than the policy impacts.

We test all hypotheses both on choices and on beliefs because treatments affect both payoffs and framing, and the latter is expected to affect choices through beliefs (Dreber et al., 2013).

4 Study site and sampling

We sampled 576 smallholder farmers in 40 communities in the municipalities of Paragominas, Ipixuna, Sao Domingo do Capim, and Irituia in the state of Parà, Brazil. Among the 576 farmers, 384 participated in the experiments reported in this article.[9] Fieldwork was carried out in October - November 2015. Following other field experiments (Cardenas and Carpenter, 2008; Perz, 2004), participants were selected in collaboration with local leaders and community organizations, attempting to get a representative sample (true random sampling turned out to be very challenging practically).

Since the experiment involved social preferences and participants were sampled non-randomly, a major threat to experiment validity is the sensitivity to non-random social ties due to village leaders being involved in the selection. We asked the community leader not to discriminate participants based on friendship, gender, participation to local association or unions, and distance from the village. When some of the invited participants did not show up (19%), the first author recruited back-up participants close to the experiment location. We test for differences in social ties and social capital across invited and back-up participants using a logit regression (see on-line material). No difference in affiliation to associations or unions is detected, nor in having more friends or relatives in the group.

The sampled participants were active smallholders, aged between 17 and 81 years. 74% of them were males. The average plot size was 50 ha. 87% of the farmers cultivated annual crops, and among them, 83% used fire. 50% of the farmers harvested at least 0.5 ha of

[9] The other 192 farmers underwent a third randomly assigned treatment that is not included in this paper.

perennial crops, mainly acai, caju and pepper. 69% of the farmers owned pasture, but only 16% of these maintained it with fire.

43% (of the full sample of 576 farmers) had suffered damages from accidental fires over the last five years. The following types of damage has occurred at least once: pastures 52%; pasture fences 46%; perennial crops 44%; annual crops 36%; and houses or other outbuildings 5% (N=240). Fires originated in only 6% of the cases from the own plot, in 41% of the cases from neighbors, and in 53% of the cases from “fires from afar”, involving several properties (N=238). When the fire did not originate from own plot, farmers were able to identify the offender in 47% of the cases. Only 4% asked for compensation, and only 2% obtained it (N=228). There is little or no (formal or informal) enforcement system, nor do farmers feel that it is legitimate to ask for compensations, fearing retaliation in other spheres of community life.

5 Results

We first analyze the impact of possible motivations for participants’ choices: norms, perceived constraints, and beliefs. Second, we present a visual inspection of choices over rounds. Third, we test the impact of drought risk treatments and policies, and the robustness of policy treatments across risk levels. Finally, we test the impact of risk levels on choices.

5.1 Participants’ motivations: norms, constraints and beliefs

In addition to the pay-off structure, we have hypothesized that social norms, feasibility constraints and beliefs about others’ behavior are important for the choices made. We examine each of these three factors in turn to see if they have an impact on participants’ behavior.

Summarizing across all sessions, participants chose A (alternatives to fire use) with a frequency of 51%, F (uncontrolled fire) of 16%, and CF (controlled fire) of 33%. Since fire control is costly (F always gives higher payoff than CF), the high number of CF choices indicates strong social preferences and/or a norm prescribing controlled fire. On average, each time a participant chooses CF he gave up, 49 points (38%) of potential earning.

A follow-up questionnaire revealed that farmers indeed strongly perceived controlling fire to be a duty: on a 1 (disagree) to 5 (agree) Likert scale, participants answered the question: “Do you think that controlling fire is a farmer duty?”, with an average score of 4.81.

The high number of CF choices might also reflect a “feasibility constraint” that participants brought into the experiment. About 56% of the farmers reported that, in real life, they would not be able to stop using fire, even if a law would forbid its use. These farmers were indeed more likely to choose CF and less likely to choose A in the experiment (Table 5).

Table 5 Summary statistics by choice

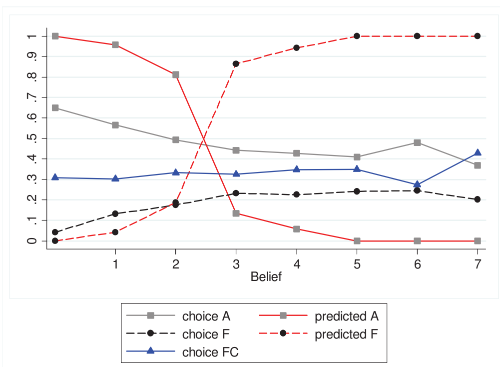
	CF	**F**	**A**	**All**
Age (years)	46	41	43	44
Male (1 = male)	74%	73%	76%	75%
Plot size (ha)	46	50	52	50
No alternatives to fire	63%	59%	50%	56%
Fire user	78%	77%	68%	73%
Suffered fire damages	41%	38%	46%	43%

Fire control measures implemented (#)	3.6	3.4	3.4	3.5
Belief below the threshold	53%	33%	61.%	54%

We also asked participants if they perceived accidental fires to be a threat for their property. Answers are heterogeneous and distributed at the extremes of the Likert scale. We found a strong correlation between perceived risk and perceived technological constraints (0.24, p<0.000) and between perceived risk and stated fire use (0.45, p<0.000). This supports one of our main hypothesis, namely that fire risk is a barrier to a transition out of fire use.

The third factor is participants' belief. Figure 1 shows that, as predicted, a higher anticipated neighborhood fire hazard (NFH) made a participant less likely to choose A and more likely to choose F, while the frequency of CF appears to be unaffected by beliefs (see also Table 5).

Figure 1 Theoretical predictions and actual choice probabilities on beliefs
(Predicted choice probabilities are not binary because switching points are averaged across policies and risk treatments)



5.2 Choices over time

We introduced two polices (PES and CAC) to promote a fire-free practice (A) or controlled fire (CF) under two drought risk scenario (increasing and stable risk). Figure 2 displays the frequencies of choices over time for each treatment group.

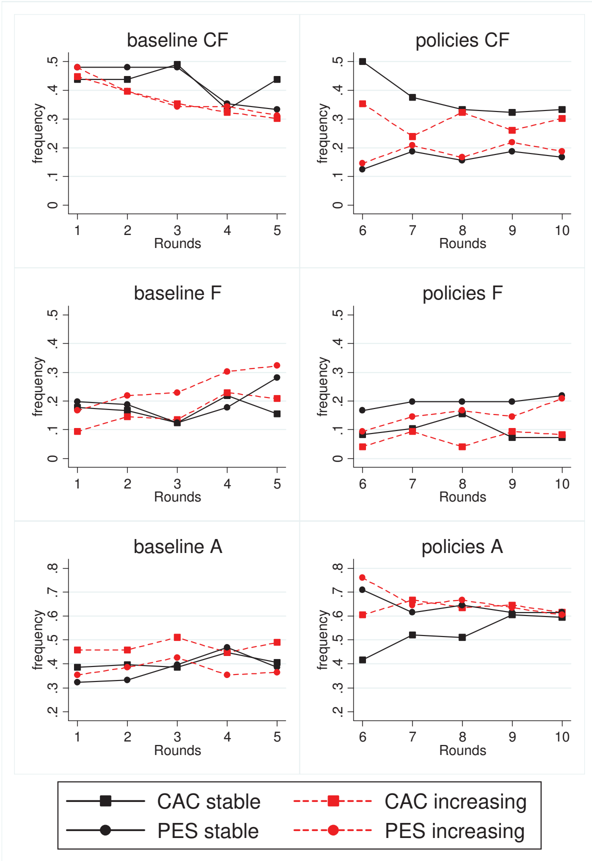
CF choices tend to decline during baseline rounds, especially under increasing risk. One explanation may be that players over time learned about actual payoffs and that the fire control norm weakened. Learning seemed especially important in the baseline rounds.

The introduction of PES reduced the number of CF choices, irrespective of the risk treatment, while CF choices did not decline under CAC. This might be the effect of an increase in salience of payoffs compared to the social norm, an institutional crowding out.

As expected, F choices increased in baseline rounds under the increasing risk treatment. Policies seemed to offset the increasing trend, and more so under CAC than PES.

Choices A remain constant during baseline rounds. The average policy impact is not visually distinguishable, because the effect varies over time and the choices converge in the last two rounds: PES has a high but decreasing impact, while the impact of CAC is increasing over time and stable across risk levels.

Figure 2 Choices across rounds



5.3 Policies and drought treatments impact

We turn to a more formal analysis of the relative merit of fire policies and drought risk treatments. We tested how policies interacted with the drought risk treatments and how robust their impact is across risk levels. Policies can impact behavior both by changing the payoffs directly and by changing the beliefs of participants, and we explicitly also test the latter effect.

We assess the impact of policies and increasing risk in a multinomial logit model. F is chosen as the base category because the natural policy question is how to reduce fire risk, i.e., the odds of choosing A or CF instead of F. To analyze beliefs about NFH, we used the same specification as for choices, but applied a Poisson regression as belief is a count variable.

Individual and session level correlations may lead to inconsistent and biased estimates and incorrect standard errors (Fréchette, 2012). We applied random effects at the individual and session levels, which capture the origin of session level correlation (Fréchette, 2012), and cluster robust standard errors at the session level. When the number of clusters is low, the asymptotic properties of clusters are not met and standard errors can be misleading (Cameron and Miller, 2015). In the latter case, we only relied on session level random effects and standard errors clustered at the individual level.

Control variables included individual age and gender as well as mean age and gender composition of the group. We also included a dummy if the participant stated to be a fire user, and a dummy if reported to have no access to real life alternatives to fire use. The inverse round trend (1/round) was included to control for learning, capturing both the round sequence as well as the difference between early and latter rounds. We control for beliefs as these may be correlated with both the treatments and the outcome variables. To test for any adaptive expectations about external fire risk, and control for the uneven (even if random) drought occurrences across sessions, we included the lag of the empirical cumulative density of drought occurrences (i.e., the lag of the sum of drought frequency in previous rounds).

The impact of policies and increasing risk are estimated in the same model, as reported in the on-line material. Interactions are set to capture the full crossed-design of the experiment. The treatment impact of increasing compared to stable risk is estimated for baseline and policy treatment rounds and reported in Figure 3. Contrary to our prediction, increasing risk *per se* did not raise the NFH beliefs, nor did it have an impact on choices. An exception was the increase of choices A during the CAC treatment rounds, which also seems at odds with our predictions. The interaction between increasing risk and CAC is analyzed and discussed further below.

The non-significant impact of increasing risk may be best explained by participants inability to properly deal with probabilities, a concept proved to be difficult to understand (Slovic, 1987; Tversky and Kahneman, 1992). While the drought probabilities are fully explained to the participants in each round, they may rather adapt their expectations, to the recent drought exposure in the experiment. Indeed, we find that participants that were – by chance – more exposed to droughts in previous rounds played less A and CF (p=0.000 and p=0.013, respectively; Wald test of joint difference from 0). One explanation is that the drought experience increases their subjective probability of a drought occurring, and thus make them more likely to choose F.

Figure 3 Increasing drought risk treatments impact
(Multinomial logit and Poisson regression, log odds ratio and log of expected count; 90% and 95% CI; full regression results are available in the on-line material)

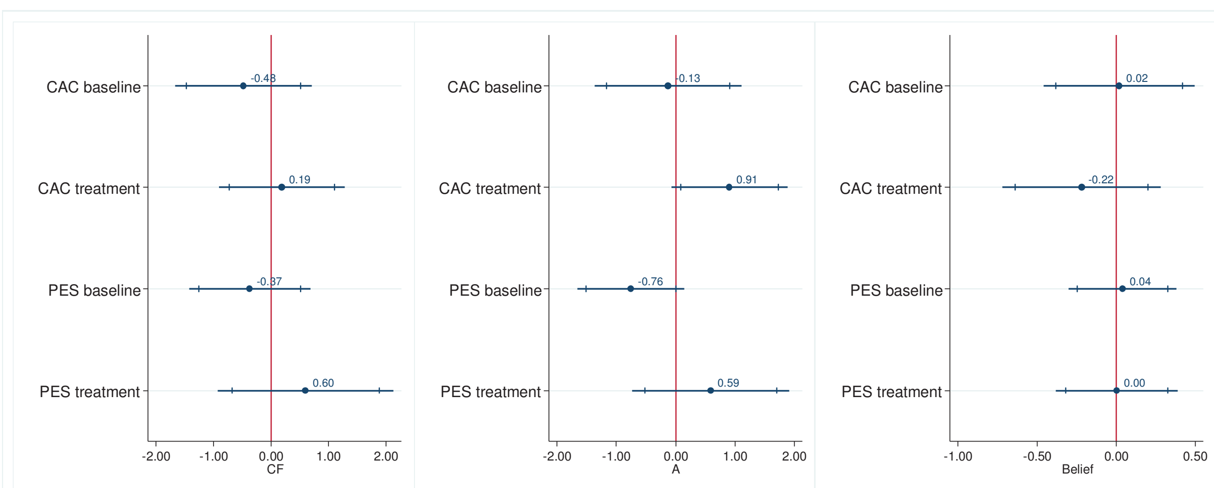


Figure 4 reports the impact of policies for each drought risk scenarios, while Table 6 presents additional Wald tests across treatments. Three results stand out. First, CAC and PES increased A choices by roughly the same magnitude, while PES reduced CF choices, possibly due to an institutional crowding out of the fire control norm. Second, CAC had a unique belief-mediated impact when combined with the increasing risk treatment. Third, in spite of increasing risk having no impact in itself, both policy treatments performed better under increasing risk. In a separate regression, we found that their impact is constant across different levels of risk (see on-line material). The last two findings point to some important interaction between drought risk and policies. This might be the consequence of more risk reducing the odds of choosing CF or A instead of F during baseline rounds. This is tested in the next section. When risk increased, policies might have been perceived as more supportive than under stable risk, as we return to in the discussion.

Being a fire user or reporting technological constraints to end fire use had no direct impact on choices, but indirectly increased fire use through beliefs. This might have occurred because real life risk perception, fire use and perceiving a technological constraint are strongly correlated. This is also coherent with Dreber et al. (2013); framing mainly operates through changing beliefs, rather than directly through (perceived) payoffs.

Figure 4 Policies treatments impact
(Multinomial logit and Poisson regression, log odds ratio and log of expected count; 90% and 95% CI; full results are available in the online material)

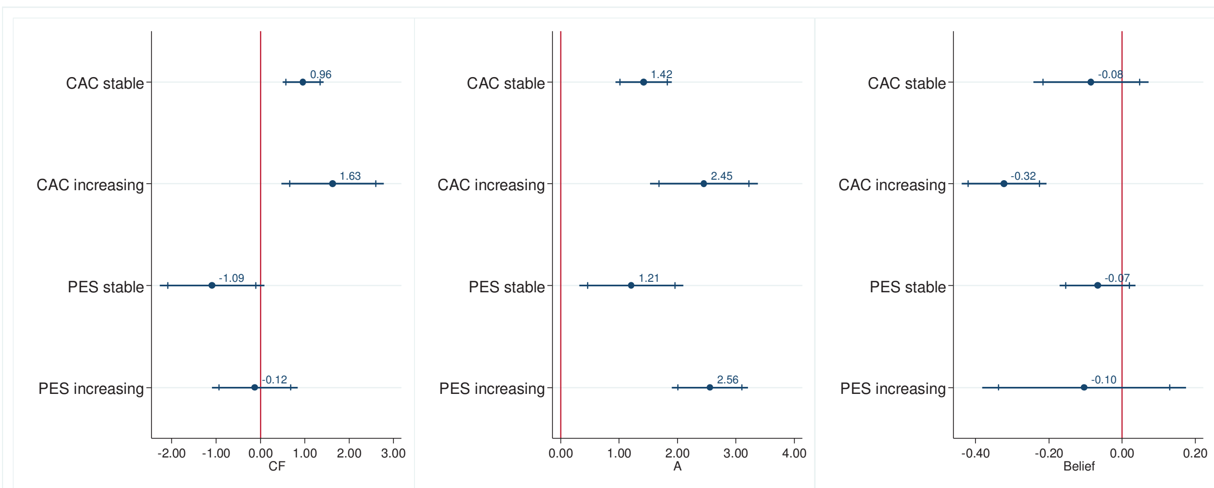


Table 6 Wald tests of treatment impacts difference (p-values)

	A	CF	Beliefs
CAC increasing vs. stable	0.025	0.147	0.008
PES increasing vs. stable	0.008	0.106	0.405
CAC stable vs. PES stable	0.342	0.001	0.428
CAC increasing vs. PES increasing	0.429	0.011	0.078

5.4 Impact of drought risk levels

Drought risk is expected to lowers the expected payoff of choosing A in two ways: directly by reducing its expected payoff, and indirectly by raising the beliefs about other players not controlling their fires.

To test the overall impact of the risk magnitude on choices, we followed the same specification outlined above, and regressed each choice variable on an interaction term between risk levels (0 to 60%) and a dummy indicating policy treatment rounds (see on-line material). Admittedly, our results might suffer from an order effect because the levels of risk are not randomized across rounds, as we deemed increasing risk to be of special interest, simulating a climate change scenario.

Figure 5 Risk level impact on choices and beliefs
(Multinomial logit and Poisson regression, log odds ratio and log of expected count; 90% and 95% CI; full results are available in the on-line material)

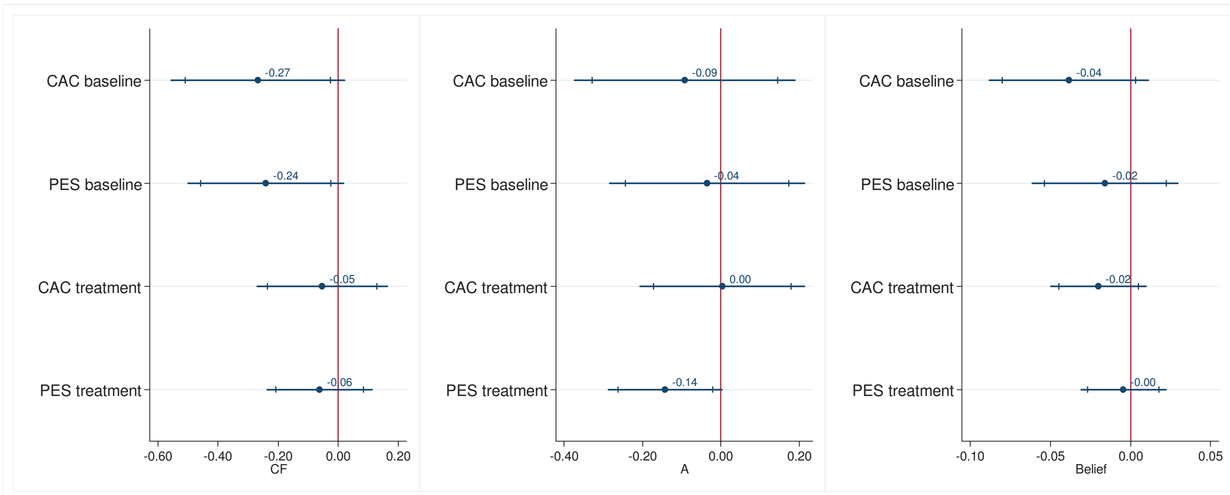


Figure 5 reports the impact of risk on choices and beliefs. During baseline, as risk increases, less CF and more F choices are chosen, but not less A choices. We may interpret these findings as if the exogenous risk broke down the fire control norm and created a feeling of anomie among farmers: despite controlling own fire, fires were still occurring.

When policies were introduced, risk did not affect CF choices anymore, possibly because the policies were supportive of the fire control motivation.

During PES treatment rounds, the impact of risk on A choices was more pronounced compared to baseline rounds. This negative impact might be ascribed to a potentially deceptive effect of mixed incentives. Because more players chose A under the PES treatment, they were more likely to be sensitive to fire risk.

The negative impact of risk on A choices was only significant for PES and not for CAC, we suspect this to be the effect of CAC being supportive of the local fire control norm, making it more salient compared to payoffs.

Farmers response to drought risk hints that the observed increase in the number of fires during drought years might be not only a consequence of increased fuel load, but also the consequence of a reduction in the incentive to control fire, as posited by Nepstad et al. (2001). Specifically, our result hint that there might be a human mediated impact of droughts on fires.

6 Discussion

6.1 Experimental policy mechanism evaluation and external validity

The evaluation of tropical forest conservation measures often suffer from poor data availability and except for protected areas, quasi-experimental situations are rare (Börner et al., 2016). These problems are exacerbated in the case of fires in the Brazilian Amazon (Morello et al., 2017). Local policy implementations are scattered and poorly documented.

The analysis of satellite data alone is unlikely to shed light on the reasons underlying policy effectiveness (Carmenta et al., 2011). Survey data are likely to be affected by over and under-reporting due to taboos and conflicts connected with fire accidents (Cammelli, 2014; Carmenta, 2013). Finally, the endogenous social effects, from the individual to the group and vice versa (Manski, 1993) generated by fire risk externalities cannot be easily accounted for using survey data (cf. Bowman et al., 2008).

Framed field experiments (FFEs) cope with these shortcomings, and help to identify the causal mechanisms behind the behavioral impact of policy instruments (Ludwig et al., 2011). Experiments can also inform policy makers about the potential impact and interaction with specific contextual factors *before* implementation (Handberg and Angelsen, 2015). Yet, caution is needed in generalizing from experimental tests on the relative merits of policies; the outcomes are likely to be influenced by the artificiality of the setting, the treatment dose (level of PES payment, and the probability and level of the fine), and threshold effects may occur.

The participants in our experiment have complex motivations that, taken together, support the external validity of the experiment. First, payoffs and expectations about others' choices (NFH) matter: when a participant believes others to choose more uncontrolled fire (F), he is more likely to use fire himself. Second, perceived fire risk is strongly correlated with stated fire use in real life, which in turn affects expectations in the experiment. This suggests a causal interpretation of fire risk perception on fire use both in real life and in the experiment. Third, a strong fire-control norm causes a high frequency of CF choices, even if the CF choice is always strictly dominated when only considering the payoffs. Questionnaire responses and field evidence suggest that the frequent choice of CF is best explained by the existence of a fire-control norm.

6.2 There is a human mediated self-reinforcing loop between droughts and fires

We hypothesized that increasing fire risk might stimulate uncontrolled fire use among Amazonian farmers, because it has a direct impact on the benefits of controlling fire (Nepstad et al., 2001). In addition, increasing risk *per se* might foster uncontrolled fire use because it engenders self-fulfilling expectations about other farmers *not* controlling fire. We find no evidence of this second effect. We find, however, evidence of a higher risk leading to less controlled fire in baseline rounds and less fire free technologies under PES treatment.

Although farmers respond to changes in risk levels, they fail to maximize the expected value of choices across the ten rounds. Failing to account fully for risk *a priori*, they change their behavior after a random drought occurrence. This finding suggests that after experiencing fires, investments in alternative techniques might be lower, and that a higher level of drought risk makes fire control slacker. Therefore, the negative impact of droughts on fires might be partly mediated by farmers controlling less fire, slowing down the uptake of alternative techniques, and producing more ignitions.

Exogenous drought risk shifts the responsibility of fires from participants to nature, hampering the positive impact of the fire control norm. Although on average there is no significant impact of increasing risk *per se*, we find that players are less likely to control fire as risk increases. Exogenous fires might ignite a feeling of anomie in participants, especially when risk is increasing, because fires occur irrespectively of compliance with the norm. Policies on the other hand might crowd in the fire control norm because they offer a focal point for coordination. This might explain why the policy impact is higher when risk is increasing.

6.3 Command and control outperforms payments for environmental services

We find that CAC increases and PES reduces the odds of choosing CF compared to F. The latter result might be due to either a normative crowding out effect or risk aversion.

Muradian et al. (2013) argue that crowding out of intrinsic motivations is likely to occur when the task is characterized by a high pro-social component and the context is marked by social norms, which characterize the fire control in our study site. Both CAC and PES have the potential to crowd-out social preferences because they might increase the relative salience of payoffs.

Any difference between CAC and PES might be due to risk aversion, with risk-averse participants being more responsive to the fine. Risk aversion increases (decreases) the expected payoff difference between F and A (CF) compared to PES, making the two treatments theoretically not equivalent any longer. Both PES and CAC might have reduced CF choices because of a crowding out effect of social preferences, however, CAC might more than compensate this negative effect because risk averse participants are more responsive to potential fines.

A recent simulation study by Morello et al. (2017) finds that subsidies to mechanization would perform better than CAC, in part due to the high monitoring and enforcement difficulties of sanctioning smallholders (Börner et al., 2015; Godar et al., 2014). They also point to an interesting dilemma and trade-off between effective fire and deforestation policies. Mechanization subsidies (and PES payments in general) might increase farming profitability, putting more pressure on forests. This calls for several policy instruments to achieve multiple objectives.

Our experimental results cannot account for general equilibrium effects, indirect land use change and insufficient monitoring and enforcement capacity. Yet, our design allows to analyze closely the strategic interaction involved in fire management and to account for exogenous drought shocks. Our results suggest, that if monitoring of smallholder was implemented, for instance by increasing monitoring resolution (cf. Assunção et al., 2014), less uncontrolled fires would occur than under PES.

7 Conclusions

We conducted a FFE to test the *ex-ante* impact of policies and drought risk on smallholder farmers' use and control of fire. We find that perceived accidental fire risk correlates with more fire use in real life and that drought induced fire risk increases the uncontrolled use of fire in the experiment, in conformance with the Nepstad et al. (2001) hypothesis. This occurs directly through reduced expected benefit of investing in alternative techniques and indirectly, by undermining local fire control norms.

Our findings suggest that alerts about fire risk, proposed by, *inter alia,* Moran et al. (2006) and by Brondizio and Moran (2008), might have an ambiguous impact on fires. If a high drought risk is announced, farmers have more information to make decisions. Socially conscious farmers may be reluctant to "play with fire". Nevertheless, the direct economic incentives suggest the opposite response. A higher drought risk may induce negative expectations and therefore reduce coordination, because each farmer's benefit of not using fire and to invest in fire control are reduced. The outcome depends on the impact of drought risk on farmers' beliefs and on complementary policies, such as CAC and PES. We have shown that these work best under a scenario of increasing drought risk (climate change), and that the mediating policy impact is robust across risk levels.

We find that command and control scores better in reducing uncontrolled fires than payments for environmental services, partly through changes in believes. The enforcement of the Forest Code would reduce fires and promote the uptake of alternative techniques, and also meet the high demand for justice of local farmers. 43% of them suffered at least one fire accident in the last 5 years of which only 2% obtained a compensation for the consequent damages.

56% of the smallholders in our sample reported to not be able to farm without fire, even if the law forbid it. Despite CAC seemingly being a superior policy instrument, complementing it with enabling measures such as PES and technical assistance are needed both for equity reasons and to generate win-win outcomes and political and popular acceptance. The measures would match smallholders' norm and avoid the negative welfare effect of smallholders alone carrying the fire control costs.

8 Acknowledgment

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10 On- line appendix

10.1 Test of selection bias induced by participants being invited by community leaders.

Table 7 Test of selection bias induced by participants being invited by community leaders (Logit regression)

	Invited participant
N of friends in the experiment	0.096
	0.073
N of relatives in the experiment	0.096
	0.123
Participate in association	0.306
	0.288
Participate in union	0.307
	0.330
Age	0.009
	0.011
Male	-0.112
	0.330
Years in the community	0.001
	0.012
Constant	0.368
	0.637
N	366
Chi2 test (p-value)	0.3632

10.2 Policies and drought risk treatments

Table 8 Policies and drought risk treatments impact (multinomial logit and Poisson regression, log odds ratio and log of expected count).

	A	CF	Beliefs
PES group	0.094	0.259	0.144
	0.647	0.508	0.209
Increasing risk	0.100	0.116	-0.210
	0.656	0.468	0.229
PES group * increasing risk	-0.635	-0.598	0.254
	0.868	0.666	0.280
Treatment rounds	1.101	1.619	-0.043
	0.403***	0.307***	0.128
PES group * treatment rounds	-0.617	-2.749	-0.013
	0.840	0.912***	0.168
Increasing risk * treatment rounds	1.390	0.131	-0.200
	0.711*	0.699	0.158
PES group * Increasing risk * treatment rounds	-0.015	0.908	0.225
	1.206	1.427	0.272
Lag drought occurrences CDF (CAC group * stable risk * baseline r.)	-0.560	0.237	-0.037
	0.203***	0.221	0.063
Lag drought occurrences CDF (CAC group * stable risk * treatment r.)	-0.265	-0.369	-0.076
	0.141*	0.184**	0.057
Lag drought occurrences CDF (CAC group * increasing risk * baseline r.)	-0.771	-0.312	0.174
	0.295***	0.438	0.050***
Lag drought occurrences CDF (CAC group * increasing risk * treatment r.)	-0.805	-0.424	0.100
	0.171***	0.177**	0.039**
Lag drought occurrences CDF (PES group * stable risk * baseline r.)	-0.848	-0.088	0.065

	0.308***	0.176	0.043
Lag drought occurrences CDF (PES group * stable risk * treatment r.)	-0.177	-0.055	0.055
	0.224	0.255	0.044
Lag drought occurrences CDF (PES group * increasing risk * baseline r.)	-1.052	0.016	0.063
	0.264***	0.262	0.073
Lag drought occurrences CDF (PES group * increasing risk * treatment r.)	-0.407	-0.014	-0.005
	0.264	0.283	0.075
Beliefs	-0.211	-0.089	
	0.047***	0.046*	
Male group	0.011	0.013	-0.009
	0.013	0.016	0.007
Age group	-0.006	0.024	-0.010
	0.037	0.038	0.016
Age	0.015	0.014	-0.008
	0.009***	0.010	0.005*
Male	-0.005	-0.490	-0.017
	0.291	0.288*	0.109
Perceived choice constraint	-0.360	0.238	0.258
	0.308	0.312	0.116**
Inverse round trend	-0.432	1.218	0.191
	0.371	0.337***	0.073***
Years of education	0.011	-0.157	-0.011
	0.038	0.045***	0.016
Fire users	-0.165	-0.033	0.351
	0.335	0.262	0.129***
Constant	1.321	-0.882	1.471
	1.923	2.410	0.979
Var session level RE	0.954	0.311	0.170
	0.490	0.242	0.053
Var individual level RE	2.680	3.409	0.636
	0.474	0.634	0.101
Cov session level RE		0.275	
		0.168	
Cov Individual level RE		0.420	
		0.306	
N	3840	3840	3840

Standard errors are clustered at the session level. *** refer to p<0.01; ** p<0.05; *p<0,1

Table 9 Increasing risk treatment impact.

	Effect	SE	z	p	95% CI	
	CF					
CAC baseline	-0.479	0.606	-0.790	0.430	-1.666	0.709
CAC treatment	0.187	0.558	0.340	0.737	-0.906	1.280
PES baseline	-0.370	0.538	-0.690	0.492	-1.424	0.685
PES treatment	0.601	0.779	0.770	0.441	-0.927	2.128
	A					
CAC baseline	-0.128	0.630	-0.200	0.839	-1.363	1.108
CAC treatment	0.906	0.501	1.810	0.071	-0.076	1.887
PES baseline	-0.755	0.461	-1.640	0.101	-1.659	0.148
PES treatment	0.591	0.674	0.880	0.381	-0.730	1.913
	Belief					
CAC baseline	0.019	0.243	0.080	0.938	-0.458	0.496
CAC treatment	-0.219	0.255	-0.860	0.391	-0.720	0.281
PES baseline	0.041	0.174	0.230	0.815	-0.300	0.382
PES treatment	0.004	0.196	0.020	0.983	-0.380	0.388

Table 10 Policies treatment impact

	Effect	SE	z	p	95% CI	
	CF					
CAC ST	0.963	0.236	4.090	0.000	0.501	1.425
CAC INCR	1.629	0.590	2.760	0.006	0.472	2.786
PES ST	-1.095	0.602	-1.820	0.069	-2.275	0.086
PES INCR	-0.124	0.494	-0.250	0.801	-1.092	0.843
	A					
CAC ST	1.421	0.245	5.800	0.000	0.941	1.901
CAC INCR	2.454	0.469	5.230	0.000	1.535	3.374
PES ST	1.211	0.453	2.670	0.008	0.323	2.098
PES INCR	2.557	0.333	7.680	0.000	1.905	3.210
	Belief					
CAC ST	-0.084	0.080	-1.050	0.293	-0.241	0.073
CAC INCR	-0.322	0.059	-5.450	0.000	-0.438	-0.207
PES ST	-0.067	0.053	-1.270	0.205	-0.171	0.037
PES INCR	-0.104	0.142	-0.730	0.467	-0.382	0.175

10.3 Risk level impact on choices

Table 11 Risk level impact on choices and beliefs (Multinomial logit and Poisson regression, log odds ratio and log of expected count).

	A	CF	Beliefs
Risk level	-0.922	-2.672	-0.384
	1.435	1.470*	0.254
Treatment rounds	2.552	1.060	-0.371
	0.801***	0.806	0.127***
Risk level * treatment group	0.959	2.140	0.184
	1.682	1.728	0.277
PES group	-0.626	-0.248	0.357
	0.706	0.631	0.204*
PES group * risk level	0.567	0.261	0.225
	1.333	1.381	0.233
treatment round * PES group	-0.501	-1.927	0.235
	0.810	0.867**	0.128*
Policy treatment round * PES group * risk level	-2.024	-0.346	-0.070
	1.791	1.911	0.299
Lag drought occurrences CDF (CAC group * baseline rounds)	-0.244	0.417	0.250
	0.495	0.512	0.090***
Lag drought occurrences CDF (CAC group * treatment rounds)	-0.738	-0.300	0.127
	0.252***	0.266	0.041***
Lag drought occurrences CDF (PES group * baseline rounds)	-0.749	0.545	0.055
	0.401*	0.363	0.069
Lag drought occurrences CDF (PES group * treatment rounds)	-0.140	0.136	-0.001
	0.261	0.295	0.048
Beliefs	-0.206	-0.048	
	0.054***	0.057	
Male groups	0.008	0.028	-0.009
	0.023	0.020	0.007
Age group	-0.008	0.025	-0.015
	0.063	0.056	0.021
Inverse round trend	0.322	0.703	-0.001
	0.850	0.844	0.144
Male	0.239	-0.613	-0.108
	0.386	0.429	0.157

Age	0.012	0.023	-0.013
	0.014	0.015	0.005**
Perceived choice constraint	-1.200	-0.364	0.591
	0.416***	0.458	0.161***
Years of education	0.037	-0.101	-0.045
	0.053	0.059*	0.021**
Fire user	0.333	0.551	0.327
	0.505	0.545	0.197*
Constant	1.465	-1.691	1.942
	3.438	3.071	1.116*
Var session level RE	1.328	0.673	
			0.111
Var individual level RE	2.570	3.328	
			0.652
Cov session level RE	0.407		
	0.382		
Cov Individual level RE	0.651		
	0.502		
N	1920	1920	1920

*** refer to p<0.01; ** p<0.05; *p<0,1

Table 12 Impact of risk levels on choices and beliefs.

	Effect	SE	z	p	95% CI	
	CF					
CAC baseline	-0.267	0.147	-1.820	0.069	-0.555	0.021
PES baseline	-0.241	0.132	-1.830	0.068	-0.500	0.018
CAC treatment	-0.053	0.110	-0.480	0.630	-0.270	0.163
PES treatment	-0.062	0.089	-0.690	0.488	-0.236	0.113
	A					
CAC baseline	-0.092	0.143	-0.640	0.521	-0.373	0.189
PES baseline	-0.035	0.127	-0.280	0.780	-0.284	0.213
CAC treatment	0.004	0.107	0.030	0.972	-0.206	0.213
PES treatment	-0.142	0.074	-1.930	0.054	-0.287	0.003
	Beliefs					
CAC baseline	-0.038	0.025	-1.510	0.130	-0.088	0.011
PES baseline	-0.016	0.023	-0.680	0.494	-0.061	0.030
CAC treatment	-0.020	0.015	-1.320	0.187	-0.050	0.010
PES treatment	-0.004	0.013	-0.330	0.741	-0.031	0.022

10.4 Policy impacts across risk levels

It is desirable that fire policies impact is robust across drought risk levels. We run a multinomial logit regression interacting risk levels and policy treatments under increasing risk (Table 13). We test whether policies treatment impact is constant across drought risk by running a Wald test of the interaction coefficients (Table 14). Both CAC and PES have a robust impact on choices and on beliefs. Yet, droughts occurrences (i.e. the lag drought occurrences CDF) increases beliefs and reduces A choices suggesting that fires do reduce the uptake of fire free technologies, and that special measures are required to counteract the effect of drought occurrences, regardless of the underlying drought risk.

Table 13 Impact of policy treatments for varying levels of risk (Multinomial logit and Poisson regression, log odds ratio and log of expected count).

	A	CF	Beliefs
Beliefs	-0.214	-0.052	
	0.055***	0.058	
CAC impact if risk=0	-6.605	2.776	0.535

	7.042	8.189	1.285
CAC impact if risk=1	-1.728	0.789	-0.081
	3.078	3.566	0.559
CAC impact if risk=3	0.673	2.458	-0.109
	1.933	2.202	0.338
CAC impact if risk=5	1.573	2.149	-0.125
	1.406	1.587	0.246
CAC impact if risk=6	1.990	2.652	-0.133
	1.214	1.341**	0.201
PES impact if risk=0	-7.101	-0.142	0.748
	6.664	7.766	1.229
PES impact if risk=1	-2.439	-0.289	0.190
	2.706	3.152	0.504
PES impact if risk=3	-1.096	-0.649	0.127
	1.480	1.726	0.280
PES impact if risk=5	0.401	0.330	0.102
	0.944	1.074	0.178
PES impact if risk=6	0.000	0.000	0.000
	.	.	.
PES group if risk=0	-0.716	-0.267	0.452
	0.821	0.752	0.213**
CAC group if risk=1	-6.080	0.163	0.587
	4.235	4.921	0.774
PES group if risk=1	-6.537	-0.017	0.896
	4.274	4.946	0.799
CAC group if risk=3	-7.625	0.257	0.617
	5.625	6.544	1.029
PES group if risk=3	-8.160	-0.126	0.964
	5.671	6.585	1.052
CAC group if risk=5	-9.477	-0.732	0.563
	6.328	7.362	1.158
PES group if risk=5	-9.685	-0.477	1.100
	6.372	7.419	1.182
CAC group if risk=6	-9.686	-0.673	0.627
	6.749	7.853	1.235
PES group if risk=6	-9.910	-1.058	1.185
	6.954	8.073	1.292
Lag drought occurrences CDF (CAC group * baseline r.)	-0.154	0.507	0.271
	0.510	0.531	0.092***
Lag drought occurrences CDF (CAC group * treatment)	-0.720	-0.287	0.128
	0.258***	0.274	0.042***
Lag drought occurrences CDF (PES group * baseline)	-0.810	0.689	0.024
	0.424*	0.392*	0.073
Lag drought occurrences CDF (PES group * treatment)	-0.111	0.285	-0.012
	0.288	0.325	0.051
Male group	0.009	0.029	-0.009
	0.023	0.021	0.008
Age group	-0.007	0.023	-0.014
	0.063	0.057	0.021
Inverse round trend	-11.084	1.934	1.001
	8.389	9.774	1.537
Male	0.241	-0.626	-0.108
	0.389	0.435	0.157
Age	0.012	0.023	-0.013
	0.014	0.015	0.005**
Perceived choice constraints	-1.210	-0.373	0.592
	0.421***	0.465	0.161***
Years of education	0.037	-0.104	-0.045
	0.054	0.060*	0.021**

Fire users	0.347	0.568	0.327
	0.510	0.554	0.197*
Constant	12.927	-2.775	0.852
	8.886	10.107	1.872
Var session level RE	1.354	0.721	0.112
	0.618	0.450	0.064
Var individual level RE	2.630	3.449	0.652
	0.616	0.827	0.092
Cov session level RE	0.435		
	0.398		
Cov Indivisual level RE	0.679		
	0.515		
N	1920	1920	1920

*** refer to p<0.01; ** p<0.05; *p<0,1

Table 14 Impact of drought risk on policy treatment impact, p-values of Wald test of joint difference from zero, increasing risk treatment only.

	CF	A	Beliefs
CAC	0.228	0.577	0.639
PES	0.777	0.158	0.795

10.5 Instructions

Dear all, thanks for accepting our invitation.

First of all, we are going to explain the activities we are going to carry out, then we are going to play the game, and finally we will conduct a short survey. Let's start.

This game is a different and amusing way to actively engage in a research project about agricultural techniques, use and control of fires. After playing the game, we will ask you to answer a short questionnaire.

The reason why money is involved, is to replicate a situation close to your real life one. Using money, your choices will have a consequence for you. This is a new kind of research, rarely implemented. It is very different from other kind of research in which you might have been involved in the past, present, or you will be involved in the future. Therefore, do not expect payments from other researcher with whom you may be asked to collaborate.

All your choices are confidential, and your name will not be revealed to anyone. The number that you received will be the only identifier of your information.

This game is different from other games or surveys in which you or other people in this community might have been involved. Therefore, comments that you heard from other people does not necessary apply to this game.

In the end of the game, the points that you are going to earn will be converted in R$, the rate is 1R$ for each 80 points. All the funds are made available by a research institution.

[After distributing the baseline payoff table]

Let's now explain the rules of the game. Please, pay the highest attention to the instructions. If you understand instructions, you will be able to make better choices in the game. If you have any question, don't hesitate to raise your hand and ask us.

In this game each of you own a farm of the same size. The other players are your neighbors. You have to make decisions about how to cultivate your land: in the first option, called F, you can use fire, for example: to slash and burn or for pasture maintenance. This does not means that you don't have other plantations on your farm, but the main produces come from *roça* and pastures.

If you decide to use fire, you have to decide whether you will adopt any fire control measures, such as: firebreaks, backfire, to burn in the coolest hours of the day, and so forth… In this game these fire control measures allows to control the burnt, for sure it will not escape to other areas. Meanwhile fire control measures comes at some costs, due to additional work and a lower final quality of the burnt. Controlled fire, CF, is the second choice showed in the table.

If you will choose not to control fire, it will escape in other areas and burn the neighbors' farms.

With the third option, called A, you adopt alternative techniques such as direct planting, use of a tractor, or mechanical or manual pasture maintenance. Perennial crops, such as agroforestry systems, açai or oil palms are also plantations that do not require fire use.

In each round of the game you are going to chose which one of these three options you prefer to implement, and each one will lead to a different earning:

- If you choose to use fire you will always earn 100 points

- If you choose to use fire and to control it, you will always earn 70 points, 100 minus the 30 points' cost of fire control measures.

If you choose to use altenatives to fire use you can earn up to the double of what you would earn with fire, because of perennials and intensive agriculture. The earning is of 200 points. However, since these plantations can accidentally burn, you can loose a part of your earning. This depends on how many of your neighbors choose F, to use fire without controling it. On the other side of the paper sheet, the big green table shows the earning of each choice for each number of neighbors who chooses F, that are listed on the first column. Line 0 corresponds to 0 neighbors choosing F, line 1 correspond to 1 neighbor choosing F, line 2 to 2 neighbors choosing F and so on until line 7, which indicate the earning of each choice when 7 neighbors choose F. As you can see from this table, if you choose A, for each neighbor that burns without control you are going to loose some points, but the other cultivations, F and CF, ensure a constant earning. Choosing A you can earn from 200 to 13 depending on how many neighbors choose F, fire without control.

Let's now turn to some examples

If you choose A, the alternatives to fire use, and one of your neighbor chooses fire without control, you are going to earn 166 points. If two neighbors choose fire without control F, you are going to earn 134, if 5 neighbors choose fire without control F, you are going to earn 53, and so forth. But if you choose F yourself, you always earn 100 points, and if you choose controlled fire CF you always earn 70 points.

The others are going to make their choices at the same time as you, so you don't know how many of your neighbors are going to use fire and if they are going to control it or not. You cannot chat with your neighbors. So, you have to guess the others' choices. Accordingly, you can help yourself with the payoff table to decide what to plant.

One more example: if 5 neighbors are going to use fire without control you can earn 100 if you farm with fire, 70 if you farm with fire and control it and 53 if farming without fire. But if 2 neighbors are going to use fire without control you can earn 134 by choosing crops without fire, always 100 if using fire and 70 if using fire and controlling it.

Do you have any questions? Did you understand how the payoff table works?

[Answering questions]

Apart from fire coming from neighbors, there is also another source of risk: the risk of fires coming from afar. This happens, for instance, during years with less rain, or when pastures get dry, or if somebody from afar lose control over his fire, or throw a cigarette but without extinguishing it, etc etc.

If a fire from afar occurs you lose more of your fire free crops. This damage cumulates to the damages caused by the fires from neighbors.

If a fire from afar occurs, you are going to earn the value specified in the smaller table, the red one on the bottom right side of the paper.

If 5 neighbors used fire without control and if a fire from afar occurs, you are always going to earn 100 points if you farm with fire, 70 if you farm with controlled fire, and 0 if you chose alternatives to fire use.

Another example: If you think that 2 neighbors are going to use fire without control, you can earn 100 points if farming with fire, 70 if you farm with controlled fire and only 9 if you chose alternatives to fire use and a fire from afar occurred; but if the fire from afar does not occurs you would earn 134.

[Showing payoffs on the table]

Any questions?

[Answering questions]

In order to decide if a fire from afar will take place, after making your choice, we are going to roll a 10-sided dice like this one.

[Showing the dice]

IF STABLE RISK TREATMENT APPLIES:

If the dice falls on 1, 2 or 3 a fire from afar occurs. This corresponds to a fire risk of 30%

IF INCREASING RISK TREATMENT APPLIES:

The risk will increase along the game, as if the climate gets drier and drier along the years.

In the first round, no dice is rolled and there is no risk of fire from afar.

In the second round, there will be a fire from afar if the dice falls on 1. This corresponds to a fire risk of 10%

In the third round, there will be a fire from afar if the dice falls on 1,2 or 3. This corresponds to a fire risk of 30%

In the fourth round, there will be a fire from afar if the dice falls on 1,2,3,4, or 5. This corresponds to a fire risk of 50%

In the fifth round, there will be a fire from afar if the dice falls on 1,2,3,4,5 or 6. This corresponds to a fire risk of 60%

In the sixth round, no dice is rolled and there is no risk of fire from afar.

In the seventh round, there will be a fire from afar if the dice falls on 1. This corresponds to a fire risk of 10%

In the eighth round, there will be a fire from afar if the dice falls on 1,2 or 3. This corresponds to a fire risk of 30%

In the ninth round, there will be a fire from afar if the dice falls on 1,2,3,4, or 5. This corresponds to a fire risk of 50%

In the tenth round, there will be a fire from afar if the dice falls on 1,2,3,4,5 or 6. This corresponds to a fire risk of 60%

[Showing a table that presents risk and rounds]

During the game, you can consult the two payoff tables. I suggest that you always compare the choices that you want to make in both scenarios: with and without a fire from afar occurring.

Do you have any questions?

[Answering the questions]

[Distributing paper tips for choices and beliefs collection]

Now it is very important for the success of the game that you keep silence in the room.

Overall, you are going to play two blocks of 5 rounds each. After the first 5 rounds we are going to interrupt the game and give you further instructions.

On one of the sides of the paper tip there is a question: How many of your neighbors are going to choose F? You should answer the number of neighbors that you think are going to choose fire without control, F, and that might represent a risk for you. This helps you to make choices based on the payoff tables. Each time that you guess the right number of neighbors that chose fire without control, F, you are going to earn 30 additional points.

After answering the question, on the other side of the paper tip, you are going to mark your farming choice:

- F farming with fire
- CF farming with controlled fire
- A farming with alternatives to fire use

Be careful that nobody see your choice. This is very important for the success of the game! If you are going to chat with each other the results are going to be invalidated and we will have to suspend the session, and nobody will get any reward.

After making your choice we are going to tell you how many of you actually choose F, CF or A, and if a fire from afar occurred or not.

This routine is going to be repeated each round

Do you have any questions?

[Answering questions]

Now we are going to play a trial session. This round is only to learn, and there is not going to be any compensation.

Remember that you cannot chat with each other during the game.

[Ask participants to sit backward to the circle]

[Up to two trial rounds are played and eventual questions are answered during the practice]

Now we are going to start the game. All your choices will now be remunerated!

[After 5 rounds]

The first part of the game is over. For the next five rounds we are going to introduce a new rule.

[Announce the rule]

IF POLICY IS COMMAND AND CONTROL

The government is intensifying controls, and if it finds out, punishes those who let the fire escape.

In each round, in order to know if a police control is going to happen, after you made your decisions, we are going to roll a 6 sided dice.

If it falls on 1 or 2 (around 33% of risk), there is going to be a police control, and if you used fire without control, you are going to receive a fine of 73 points, which is subtracted from your round earning. So, if a police check occurs, F only yields 27. Be aware that the fine does not affet yields from past or future rounds.

IF POLICY IS COMMUNICATION

An NGO and the Government promote the adoption of community rules to manage and control fires. Regular meetings are organized before the fire season and the neighbors can discuss on how to use fire. In each round before making your choices, you are allowed to discuss with your neighbors for a minute. After that period any other form of communication is forbidden again.

[During each minute of communication, participants are allowed to turn inward the circle, after that, participants turn outward again beofre making their choices]

IF POLICY IS PAYMENTS FOR ENVIRONMENTAL SERVICES

[Distributing the new payoff tables]

An NGO and the Government decide to start a project of payments for environmental services in your area to promote environmental conservation. They make the following offer: if you choose to invest in alternatives to fire use you are going to receive an additional payment of 30 points. Here goes a new payoff table.