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THE EFFECT OF RISK, AMBIGUITY, AND COORDINATION ON FARMERS' ADAPTATION TO CLIMATE CHANGE

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SUMMARY The risk of losses of income and productive means due to adverse weather associated to climate change can significantly differ between farmers sharing a productive landscape. It is important to learn more about how farmers react to different levels of risk, under measurable and unmeasurable uncertainty. Moreover, the costs associated to investments in reduced vulnerability to climatic events are likely to exhibit economies of scope. We explore these issues using a framed field experiment that captures realistically the main characteristics of production, and the likely weather related losses of premium coffee farmers in Tarrazu, Costa Rica. Given that the region recently was severely hit by an extreme, albeit very infrequent, climatic event, we expected to observe, and found high levels of risk aversion, but we do observe farmers making trade offs under different risk levels. Although hard to disentangle at first sight given the high level of risk aversion, we find that farmers opt more frequently for safe options in a setting characterized by unknown risk. Finally, we find that farmers to a large extent are able to coordinate their decisions in order to achieve a lower cost of adaptation, and that communication among farmers strongly facilitates coordination.

Keywords: risk aversion, ambiguity aversion, technology adoption, climate change, field experiment

JEL: C93, D81, H41, Q16, Q54

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The international workshop on “The Social Dimension of Adaptation to Climate Change” – jointly organized by ICCG, CMCC and FEEM - held on February 18-19, 2010 at Palazzo Querini Stampalia in Venice – has been a special occasion to face an emerging aspect of the climate change issue, the social dimension and the consequences of climate change for human societies.

This perspective has been neglected in climate change studies, even if in recent years a social science-oriented approach investigating social system dynamics and individual behaviour in connection with climate change has emerged and the importance to identify the impacts of the climate policy architecture on societies - and especially on the world’s poorest and most vulnerable people- is today included in the climate agenda.

A variety of scholars and practitioners enriched the debate on what social adaptation means in different contexts and geographical areas: the success of adaptation will largely depend on the extent to which individuals and societies will be willing to accept change and to adopt lifestyles and behaviours that reduce social-environmental vulnerabilities by improving adaptive capacities and resilience.

In order to overcome the existing trade-off between the two main avenues of climate policies, adaptation and mitigation, which labels adaptation as a local-based intervention while mitigation actions are seen as the first best measures, the papers presented at the Venetian workshop contributed to highlight the importance of developing context-specific analyses as a complementary knowledge to reconcile climate actions with the development and growth agenda especially for vulnerable countries.

Climate research will be challenged in the near future by the need to develop an holistic approach to climate impacts, considering physical and environmental ecosystems as well as the human and social systems. This perspective will provide an effective foundation to adaptation to future climate change and will lead to the inclusion of equity and social justice issues into climate policies.

1. Introduction

There is an extensive literature on the effects of climate change on agriculture (see e.g. Adams, 1989; Mendelsohn et al., 1994; Schlenker et al., 2005). The early literature predicted very large costs, but these estimates were criticized for ignoring the possibility of adaptation. The IPCC (2007) defines adaptation as “*the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.*” From a farmers perspective climate change can be seen as a technology shock, whose potentially negative effects can be moderated by adapting its production function in anticipation to the new reality. There is an extensive literature on agricultural technology adoption in developing countries. A lot of attention has been put on explaining why the adoption rates have been so low in these countries; see Feder et al. (1985) for a survey. A number of explanations have been put forward including credit constraints, social networks, and tenure insecurity.

In this paper, we are interested in three aspects of adaptation to climate change. First, we want to investigate the effect of the level of the risk of income losses due to

climate change on farmers’ willingness to adapt. Second, we want to explore if farmers are ambiguity averse and if that can explain adaptation behavior. Third, we want to know if and to what extent farmers are able to coordinate their adaptation efforts, if there are economies of scope in costs.

Risk and risk aversion are likely to be important factors for the farmer’s choice of production technology and inputs. In the case of climate change, the major change in risk is the increased climatic variability and the increased risk of large losses due to extreme weather and flooding. In order to investigate the role of risk and risk aversion on the farmer’s likelihood of adapting to climate change we use a framed field experiment (Harrison and List, 2004), conducted with small-scale coffee farmers in Costa Rica. In the experiment, farmers are asked to act as if the decisions reflect their actual behavior, and the experiment involved real monetary pay-offs. The experiment is similar to a standard risk experiment such as in Holt and Laury (2002). Previous risk experiments with farmers in developing countries include, for example Binswanger (1980), Binswanger and Sillers (1983), and Wik et al. (2004). In our case the experiment is framed and the values are chosen to make

it a decision whether to adapt to climate change or not. We want to test the effect of the risk of income losses on adaptation behavior.

There are several reasons for using a framed field experiment instead of using actual production data (see e.g. Antle, 1987, 1989; Pope and Just, 1991; Chavas and Holt, 1996). First, with actual production data it is difficult to disentangle adaptation due to changes in risk and risk perception from other reasons such as changes in soil fertility, or new market opportunities. Second, it is not clear whether farmers actually are aware of changes in climate over time due to global warming, as opposed to the usual climatic variability. Thirdly, climate change might bring about production conditions, particularly for extreme events, that have no historical parallel.

In addition to risk aversion, some authors argue that ambiguity aversion is a key factor hindering the adoption of new technology. In economics, the interest in unmeasurable uncertainty¹ or ambiguity was spurred by the Ellsberg paradox (Ellsberg, 1961). A number of experimental studies have shown that people are ambiguity averse; see e.g. Fox and Tversky (1995),

¹ Knight (1921) distinguished between measurable and unmeasurable uncertainty.

Moore and Eckel (2006), Slovic and Tversky (1974). For development of theories of ambiguity aversion see for example Gajdos et al. (2008) and Klibanoff et al. (2005). With ambiguity aversion we mean that there is a preference for known over unknown risks.² In the case of technology adoption, the status quo is perceived as one where the level of uncertainty is known to the agent given her experience with the old technology. On the other hand, the benefits of the new technology in good or bad scenarios are ambiguous, leading agents to reject it in favor of the old one. In simple terms, the status quo is perceived as a safe, known bet. A recent paper that uses this setting is Engle-Warnick et al. (2007) that conduct a field experiment on coffee farmers in Peru.

In the context of climate change and technology adoption, both the status quo (no adaptation) and the new state (adaptation) could be characterized by both risk and ambiguity. Climate change is a complex phenomenon, and the estimates of for example future increases in temperature or the likelihood of extreme events are very uncertain. The risks associated with not

² Klibanoff et al (2005) defines ambiguity aversion as a preference for situations that exhibit less uncertainty about the underlying probabilities: “[...]an aversion to mean preserving spreads in the induced distribution of expected utilities [...]” (p. 1852).

adapting to climate change could therefore be described as unknown or unmeasurable. If farmers are ambiguity averse, they would then be more likely to adapt to climate change when the risk of a disaster is unknown to them compared to a similar situation with a known risk. In the experiment, we will test the effect of unknown risk on adaptation behavior.

There is one other aspect that we investigate: the capacity and willingness of farmers to coordinate in pursuit of lower adaptation costs. The cost of technology adoption is potentially a function of the behavior of others. One important reason is learning from others (Bandeira and Rasul, 2006; Besley and Case, 1993). Another reason is that the costs and benefit of a technology might actually depend on how many farmers buy and use the technology due to economies of scope. This makes the adaptation decision a public good, since the value depends on how many people that adopt (Dybvig and Spatt, 1983). This opens the door for government intervention; for example, Dybvig and Spatt (1983) suggest insuring early adopters against the possibility that others do not adopt. In our experiment, we design a situation where the cost of technology adoption is lower if everybody in the group adopts. However,

players will face different risks, and ultimately have different utility functions. This means that the decision can be viewed as a coordination game, where there could be multiple equilibrium (see for example Ochs, 1995; Cooper et al., 1999).

Depending on a number of factors, including the physical and social distance between farmers, and the quality of the institutions, farmers will be more or less able to communicate with each other in pursuit of reduced costs as described above. It is then important to differentiate between situations where coordination is possible with and without communication. Experimental evidence points consistently to the fact that communication leads to increased cooperation and hence higher payoffs in common pool resource and public good settings (Cardenas et al., 2004; Ledyard, 1995; Sally 1995). Moreover, studies also show that the link is not unequivocal, as players might react negatively if they identify non-cooperating behavior in the course of group discussions. Some explanations for the effect of communication on group decisions include persuasion, verbal promises in a trusting environment, creation of a group identity that favors cooperation, and improved understanding of the game; see for example Buchan et al.

(2006), Bochet et al. (2006), and Bochet and Putterman (2008). Ostrom et al (1994) stress the latter motive, which is likely to play a larger role when the context of the experiment is increasingly complicated due to group size, task at hand, level of education, and field experimental conditions. In the experiment we investigate the extent at which farmers adapt a new technology when there are economies of scope in the adaptation cost. This is done with and without communication between the players. We also investigate conduct treatments with and without communication when there are no strategic reasons for communication, in order to isolate any learning effect.

The rest of the paper is organized as follows: Section 2 provides background information on our sample and on the study area where the experiment was conducted. Section 3 introduces the experimental design and procedure. Section 4 presents the results, and Section 5 concludes the paper.

2. Description of sample and study area

The experiment was conducted with coffee producers in the high altitude mountains and valleys of the Tarrazu region of Costa Rica. All coffee producers are organized in a cooperative, which provided our sampling frame. This organizational setting is quite

common in the country, since membership to a cooperative allows them to share the costs of coffee milling, and gain better access to commercialization chains. Still, individual farmers are completely free to make decisions on their land. The Tarrazu region is well known for its premium quality gourmet coffee, which results from the mix of high altitude, cold weather, and lots of sun. According to a census of coffee producers (ICAFE-INEC, 2007), there are 672 coffee farmers in Tarrazu; notably these make 75% of all farms in the region. Average farm size is 9.8 ha, but 56% of all the farms are smaller than 5 ha. Almost all of the farmers own their land, and in 2006 only 16% had outstanding loans on their land. This gives a picture of a prosperous region that has an equal distribution of income, but at the same time is highly vulnerable to changes in the profits of their land -- since farms are small, profits generally are just enough to cover the household's day-to-day expenses. The possibility of finding work outside the farm is limited, given that 84% of the farmers have only basic or no education.

In early 2008, the tropical storm Alma hit the region with full force. The occurrence of extreme events in this region is very rare, given that it faces the Pacific Ocean. Based

on historical records starting in 1949, there have been only five extreme events coming near to the Pacific coast of Costa Rica, and Alma was the one that came nearest to the country and furthest south (IMN, 2008). Only in two occasions, extreme climatic events originating in the Pacific Ocean have seriously affected the Central American

region, one in 2005 and Alma in 2008. The Tarrazu regions was one of the most heavily affected, with approximately 12% of all coffee plants being lost.

In total, 211 farmers participated in our experiment. **Table 1** provides descriptive statistics for the Tarrazu region based on the coffee census and for our sample.

Table 1. Background statistics of the sampled farmers and regional census data, standard errors in parentheses.

	Population	Sample
Average age in years	42	43.3 (15.6)
Male head of household	68%	69%
Education (None/Basic/High School/Univ)	6% / 78% / 8% / 3%	7% / 74% / 14% / 4%
Number of soil conservation practices at farm level	1.77	2.47 (1.42)

Source: Own estimations based on coffee census (ICAFE, 2007)

As can be seen from Table 1, our sample is highly representative of the coffee farmers in this cooperative.

3. Description of the experiment

3.1 Experimental design

The experiment had 9 rounds in total, which were needed to test our hypotheses and also test for order effects. Since we reveal previously hidden information after round 4, we were only able to have an in-built test for order effects by altering the sequence of the last 5 rounds. **Table 2** reports all nine rounds, and the first column reports the two

sequences of treatments.³ Subjects always played in groups of three, clearly identified as farmer A, B or C.

³ Henceforth we will use the first order when referring to the design of the experiment. Notably, we find no significant order effects.

Table 2. Complete design and in-built test for order effects

Round	Risk (%) for farmers A/B/C	Information about neighbors	Gains to perfect coordination	Communication
1	1/5/10	No information	No	No
2	5/10/1	No information	No	No
3	10/1/5	No information	No	No
4	Unknown	n.a.	No	No
5/7	1/1/1	Information	No	No
6	1/5/10	Information	No	No
7/5	1/5/10	Information	Yes, costs reduced 50%	No
8/9	1/5/10	Information	Yes, costs reduced 50%	Yes
9/8	1/5/10	Information	No	Yes

Risk and ambiguity aversion

Rounds 1 to 3 are essentially a standard risk experiments. Risk levels (1, 5 and 10%) were chosen to be realistic based on expert advice, and then validated with pilot studies. In our context where decisions are made annually, a 1% risk level means that farmers might face an extreme event once every hundred years. Historical data show the occurrence of extreme events in this region is indeed extremely rare. We explicitly told them to consider their group members as neighbors, but at this stage asked for no interaction between the three players. We did not give them any information about the risk level of the other group members. Farmers were also told that their annual profits in the case of no extreme event were 500,000 colones (approximately US\$1000⁴), and in the case of an extreme event affecting

his land, profits would be 50,000 colones per year. The annual cost of investing in adaptation practices was 200,000 colones. We actually made a point of making sure that all these numbers correspond to the reality of coffee farming in the Tarrazu Region, using a representative hectare of land. It is important to stress that the Tarrazu Region uses a high productivity, conventional production technology, and the soil conservation practices required to adapt to climate change are not part of this technological package. Farmers normally would not spend their capital and labor in these practices.

Round 4 was identical to the previous except that now we introduced uncertainty about the risk level. We told all group members that “*you do not know your own risk or the risk of the others. The only thing you know is that your risk could be 1, 5 or 10 out of 100. We*

⁴ At the time of the experiment 1 USD = 500 colones.

do not know your level of risk either.” We then proceeded to explain that at the end we would randomly determine which level of risk would apply for payment. Strictly, the risk is not unknown here, so this is sometimes called a situation of weak ambiguity. The main reason why we opted for this approach was to avoid subjects believing that the experiment was rigged by the researchers. Thus, it was clear to the participants that we did not have more information about the risk than what they had. The payoff of a farmer facing the weakly ambiguous situation in our experiment is then determined by two known probabilities. The first one relates to the risk

level that each farmer will ultimately face. In our case, the risk could take any of three values with equal probability. The second one refers to the probabilities of an extreme event, which in our case are 1, 5 and 10%. Hence, the expected risk is 5.3%. We therefore compare the share of subjects adapting when the risk is known and equal to 5% with the share of subject adapting when the risk is unknown but the expected value is 5.3%. Strictly we should have used other probabilities since the expected value is not exactly 5%. However, we wanted to keep the probabilities as simple as possible. **Table 3** summarizes the design of the first four rounds.

Table 3. Risk and ambiguity treatments.

Risk levels ⁵	Adapt (safe option)	Not adapt (risky option)		Degree of risk aversion if indifferent
		Bad outcome	Good outcome	
1%	300,000	50,000	500,000	3.4
5%	300,000	50,000	500,000	2.25
10%	300,000	50,000	500,000	1.75
Unknown (between 1 and 10%)	300,000	50,000	500,000	If indifferent between unknown and risk of 5%, then ambiguity neutral

⁵ Farmers faced all risk levels in one round or the other of the first 3 rounds

In Round 5, all farmers faced a risk level of 1%. This round was designed as a first introduction to information about the risk of the other farmers in the group. We then tested for differences between this treatment in order 1 (round 5) and order 2 (round 7) and found no significant differences in the distribution of the responses using a Chi-square test (p-value = 0.828).

Gains to coordination and communication

Finally, Rounds 6 to 9 were designed to test the effect of potential gains of adaptation coordination and the role of communication in increasing the likelihood of coordination. In all these four rounds, Farmers A, B and C faced a risk level of 1, 5 and 10%, respectively, and this information was known to all players. We did this in order to reduce the informational differences between treatments with and without communication. In Round 7, after stressing that they all had different risk levels, and that extreme events could affect one farmer and not the others, we told them *“if the three of you decide to adapt, the cost of adaptation is 100,000 colones. If less than three of you decide to adapt, then the cost of adaptation is the same as before, that is 200,000 colones.”* Do note that at this stage we are still not allowing any interaction between the

players, so that Rounds 6 and 7 differ only in the potentially reduced adaptation costs. Round 8 is identical to Round 7 but now we finally allowed for interaction between the three group members, which allows us to test for the role of communication when there are gains to coordination.. Finally in, rounds 6 and 9 there are no gains to coordination and hence no strategic reason for changing behavior in round 9 as a result of communication. Hence our two-by-two design allows us to isolate the use of communication as a way of gaining a better understanding of the experiment (in round 9) from using communication as a tool for coordination.

3.2 Experimental procedure

The cooperative in Tarrazu organizes yearly meetings with all its members, grouped in 11 villages. We used those meetings to invite farmers to our experiments (called workshops). The invitation was done jointly with the cooperative, and included information about the date, time and place of our workshops in each of the communities. We also mentioned that we were hoping to learn from their experience of a changing climate, and that they would have the opportunity to participate in a set of activities in which they could earn some

money, depending on their decisions as farmers. A detachable slip was to be returned to us, where name, telephone number, and location were filled by the farmer. We followed up this invitation with phone calls confirming their interest in participating. This strategy is not different from the one used by the cooperative to call for their own meetings. In total, we handed out 434 invitations and received 397 expressions of interest, i.e. slips with contact details.

A team of three highly trained field experimenters conducted all the work. Farmers were let into the room when they arrived and were randomly assigned as farmers A, B or C in chairs arranged in groups of three. We made sure that people coming together did not form part of the same group. After a prudent lapse of time, we closed the chairs available to subjects, and late comers were allowed only as observers at the back of the room.

After welcoming the subjects and telling them about the purpose of the workshop, we explained that the experiment was going to last two hours, and reassured them about the confidentiality of their individual responses. At this time we allowed people to leave if they chose to do so, but extremely few took this option and only due to lack of time. We also requested

that there should be no interaction between subjects until we specifically allowed them to communicate.

We then explained the main aspects of the experiment. We introduced the notion of climate change and most importantly described the different possibilities available to farmers as adaptation to climate change strategies. At all times we kept a neutral perspective concerning the need to invest in adaptation. We did mention that a change in precipitation and temperature, as well as in the frequency of extreme events, could negatively affect their profitability due to increased erosion, reduced soil fertility, and in the worst case, extreme losses like the ones experienced during the tropical storm Alma. Obviously, this was nothing new to the farmers.

One of the main aspects at this stage was to explain risk to the farmers. We used visual aids depicting combinations of hundred red and white dots equivalent to 0, 1, 5 and 10%. These visual representations of risk were available at all times. A tombola with 100 red and white balls was also used, mainly to relate the risk charts with the number of balls in the tombola and eventually to our payment strategy. Throughout this presentation we stressed that risk could differ between neighbors and

that the occurrence of an event was independent for all subjects. Several trials were done until all questions were evacuated.

The actual experiment started with an explanation of the setting. We told them that we wanted to learn about their decisions as farmers in nine subsequent rounds, and that at the end of the experiment we would pay them according to their decisions. We stressed that they should regard their group members as neighbors. At this stage subjects were asked to open a booklet containing an example sheet, nine decision sheets, i.e. one for each round, and an exit survey. The pages were stapled such that they could not browse forward in the booklet. The example sheet included in Annex 1 was used to explain the basics of the 9 rounds. At this stage, we introduced the payoffs and walked each farmer neutrally through the decision whether to invest or not. Again we used the tombola to show them how their payment was going to be determined according to their risk.

Finally we proceeded to explain the payment method, which is quite standard for this type of experiments. First of all, we told them that one of the nine rounds was going

to be randomly selected for a real payment.⁶ Also, given our budget limitations, we explained that an exchange rate of one in thousand was going to be used, but asked them to focus on the per hectare payoffs that corresponded with their reality as coffee producers. Notably, even our converted payment exceeded a one day worth of salary in a coffee farm, clearly enough to achieve saliency. Before starting the experiment we conducted several example payments to show both how we were going to pay but also to make it very clear that they were playing for real money. Note that all the realizations of the risks and the outcomes were made after all nine rounds had been played.

The following is the actual translated script read for Round 1. The actual decision sheets were similar to the example sheet provided in Annex 1, so the script served to guide subjects through the details of the round. Small variations in this script were needed in the rest of the rounds.

Figure 1. Translated script for round 1

CASE 1: In this case the question is whether you choose to invest or not in adaptation, given the level of risk shown in your sheet. As visual help, you can see in this slide the possible risk levels you can face. [PUT SLIDE WITH 3 RISK LEVELS]

⁶ Later in the experiment, we explained that, for Round 4 with ambiguous risk, a further random selection of risk was needed.

- If you choose to invest in adaptation, your profit is [€300.000] independently of the level of risk.
- If you choose not to invest in adaptation, your profit will depend on the risk of a natural disaster, as described in your sheet

You do not know the level of risk of other farmers. This risk could be higher or lower than yours. The other farmers do not know your risk either. Also please remember that what happens to you will not necessarily happen to the others. In practice this means that each one of you separately will draw a ball from the tombola to determine what happens to your farm. As mentioned before, the number of red balls in the tombola depends on your own risk. In some cases, there will be 5 red balls, others might have just 1 and for some there will be 10 red balls in the tombola. Please check carefully your level of risk. Will you choose to adapt or not, given that level of risk.

Do not forget that you do not know the risk of the other farmers, and that each case is a new situation that has no relation to the previous. Please do not talk to each other. Do you have any question? [WAIT] Please mark your decision in the corresponding box.

4. Results

A total of 211 observations were gathered in the 11 workshops. The following results explore our two main research questions: (i) risk and ambiguity aversion, and (ii) to what extent farmers can coordinate their adaptation decision to reduce costs, and the

importance of communication. For the first issue, we conduct our analysis based on individual observations, and for the second issue the relevant unit of observation is group decisions.

4.1 Risk and ambiguity aversion

We begin by looking at how farmers behave at various levels of risk of having their crops destroyed by extreme weather associated to climate change. At this stage of the experiment, the farmers did not know the level of risk of the other participants. Each farmer made the decision to adapt or not for three risk levels. A number of farmers were inconsistent in the sense that they adapt at a low, but not at a high, level of risk. In total, 17% of the farmers were inconsistent. At this stage of the analysis, we remove inconsistent farmers, and are left with 175 observations. In **Table 4** the number and share of farmers adapting and not adapting at the three different levels of risks are presented.

Table 4. Number of farmers not adapting and adapting under various levels of risk

Risk of crops destroyed	Degree of relative risk aversion if indifferent	Not adapt	Adapt
1%	3.4	120 (69%)	55 (31%)
5%	2.25	40 (23%)	135 (77%)
10%	1.75	9 (5%)	166 (95%)

P-value of chi-square test of difference in distribution between risk levels = 0.000

As expected, the share of farmers adapting increases as the level of risk increases, and the differences in shares are significant using a Chi-square test. The degree of relative risk aversion, assuming a constant relative risk aversion utility function which is only a function of the pay-off, is higher than 3.4 for 31% of the subjects, and the median degree of risk aversion is between 2.25 and 3.4. Consequently, the farmers are very likely to adapt to climate change, even at relatively low levels of risks. Still, given that our

experiment took place a few weeks after the occurrence of an extreme event as dramatic as Alma we think it is noteworthy that 69% of all farmers did not adapt at a risk of 1%. When the risk level increased to 10%, only 5% of the subjects do not adapt.

We next investigate if farmers are ambiguity averse. This is done by comparing the shares of subject adapting when the risk is known and when the risk is unknown. The results for the aggregate data are presented in **Table 5**.

Table 5. Number of farmers not adapting and adapting when the risk known and 5%, and when the risk is unknown

Risk of crops destroyed	Not adapt	Adapt
Known risk, 5%	40 (23%)	135 (77%)
Unknown risk (between 1 and 10%)	38 (26%)	137 (74%)
P-value, chi-square test of difference in distribution between known and unknown risk = 0.797		

The share of subjects adapting when the risk is unknown is not significantly different from the share when the risk is known.⁷ Consequently, looking at the aggregate data there is no evidence of ambiguity aversion. One problem with our test is the high share of people adapting even when the risk is 5%. Subjects already adapting when the risk is 5% could be

adapting when the risk is unknown but with an expected value of 5.3%, even if they are not ambiguity averse. In **Table 6** we report tests for the group of participants who only adapted when the risk was 10% or did not adapt at all (40 out of 175 farmers).

⁷ Since we cannot reject the hypothesis of no difference, it does not matter that the expected value in the ambiguous treatment is slightly higher than in the treatment with known risk.

Table 6. Number of farmers not adapting and adapting when the risk known and 5%, and when the risk is unknown for subsample of subjects that never adapts when the risk is known or only adapt when the risk is known and equal to 10%.

Risk of crops destroyed	Not adapt	Adapt
Known risk, 5%	40 (100%)	0 (0%)
Unknown risk (between 1 and 10%)	18 (45%)	22 (55%)
P-value, chi-square test of difference in distribution between known and unknown risk = 0.001		

By construction, none of these farmers adapted when the risk is 5%. However when they faced the ambiguous situation (with an expected risk of 5.33%), 55% of them adapted. The difference in the share of farmers adapting is highly significant, suggesting that a large share of these farmers actually are ambiguity averse. Or differently put, the fact that the risk is unknown induces more adaptation than the corresponding situation with known risk.

Finally we estimate a logit model where the dependent variable is equal to one if the farmer decides to adapt. We do this in order to explore the effect of socioeconomic characteristics as reported at the exit survey completed by all subjects. Treatment effects are included as dummy variables (we use the 5% as the baseline risk level). The results are shown in **Table 7**, standard errors have been corrected clustering.

Table 7. Logit results using the 5% risk level as baseline, dependent variable is equal to one if farmer adapts

	Description (Mean)	Marginal effect	P-value
Treatment characteristics			
Low risk (1%)	= 1 if low risk (0.25)	-0.441	0.000
High risk (10%)	= 1 if low risk (0.25)	0.242	0.000
Ambiguity treatment	= 1 if ambiguity treatment (0.25)	0.012	0.757
Subject characteristics			
Male	= 1 if subject is male (0.71)	0.138	0.026
Age	Age in years (43.33)	0.001	0.371
Big coffee farm	= 1 if number of hectares > 5 (0.27)	-0.129	0.032
Previous investment in soil conservation	Number of soil conservation measures they have taken (2.46)	0.032	0.073
Losses due to Alma	= 0 if no losses, 2 if losses larger than 250 000 colones per hectare, 1 otherwise (1.81)	-0.023	0.485
Number of subjects / observations		171 / 700	
Pseudo-R2		0.252	

Both treatment dummy variables for known risk have the expected sign and are highly significant. The ambiguity treatment has no significant effect, as expected from the aggregate tests conducted in Table 6. From the subject characteristics, we find that males have a significantly higher probability of adapting, whereas age and education have no significant effect on the behavior in the experiment. Subjects with a big coffee farm are less likely to adapt, which could be a reflection of the fact that they have more resources to overcome adverse effects without compromising their livelihood. Finally farmers who already invest in soil

conservation are more likely to invest in additional practices to reduce the effect of climate change on their land.

4.2 The role of communication and cost saving coordination

In the last part four rounds of the experiment, subjects always knew their own risk and the risk of the two other group members. The first difference between the rounds is whether subjects are allowed to communicate or not. The second difference is whether there is an incentive to coordinate on adaptation or not. As explained in Section 3.1, farmers were told that if all group

members decide to adapt, adaptation costs would be reduced by 50%. This is indeed a realistic situation, since there are economies of scope in the provision of technical assistance and purchase of equipment and materials needed for the adoption of soil conservation practices. We now focus on the

decision at the group level, and not the individual farmer. For that reason, we remove groups with less than 3 farmers, resulting in a total of 68 groups. **Table 8** summarizes the outcomes in the groups for the four treatments.

Table 8. Number of groups with different number of subjects adapting in each treatment⁸

Number of subjects adapting	Treatment 6 No gains to coordinate & no communication	Treatment 7 Gains to coordinate & no communication	Treatment 8 Gains to coordinate & communication	Treatment 9 No gains to coordinate & communication
0	3 (4%)	0 (0%)	1 (1%)	3 (4%)
1	11 (16%)	9 (13%)	6 (9%)	11 (16%)
2	32 (47%)	26 (38%)	14 (21%)	28 (41%)
3	22 (33%)	33 (49%)	47 (69%)	26 (39%)

⁸ Treatments 6-9, were played in different orders to test for order effects, but since we found no significant order effects aggregate results are reported in the table.

There are two interesting comparison that can be made. First we can test if the whole distribution of the number of subject adapting in a group is different for two treatments (Chi-square test). Secondly we can test if the share of groups actually achieving full coordination in adaptation and hence a possible cost reduction (i.e. were all three players adapt) is different for the alternative treatments (proportion test).

To begin with, let us look at treatment 6 and 7. In both cases subjects were not allowed to communicate, but in round 7 the adaptation costs were reduced if all adapted. There is a significant increase (proportion test p -value = 0.055) in the share of groups where all adapt, and hence get reduced adaptation cost, but there is no significant difference in the overall distribution. (Chi square test p -value = 0.111). So farmers are able to coordinate only to a limited extent if they cannot communicate with each other, and the pattern of “failed” coordination efforts is not different in both cases. The question is what happens if we allow for communication, as in treatment 8 (compared to 7). Communication in the pursuit of reduced adaptation costs achieves a significant change in the distribution of responses (Chi-square test p -value = 0.053) and in 69% of the groups all subjects adapts,

thereby reaping the benefits of coordination. This share is significantly different from the share in treatment 7 (proportion test p -value = 0.015). This result is further strengthened if we compare treatments 8 and 9. In round 8 communications is allowed and if coordination is successful, will lead to reduced costs. In round 9, communication is also allowed, but is inconsequential in terms of costs. The increase in number of groups where everybody adapts is high and significant when cost reductions are at stake compared with no gains to coordination (proportion test p -value = 0.001). The difference in distributions is also significant using a chi-square test (p -value = 0.004). In order to test the effect of communication alone, we can compare treatments 6 and 9, which are not significantly different in terms of the distribution of responses (p -value = 0.896) or the share of groups coordinating (p -value = 0.473). Hence communication has no effect on farmer’s decisions in the absence of further gains from coordination. In our experimental setting, communication is thus not important in the sense of learning and understanding the experiment, but it is important for strategic coordination reasons.

5. Discussion

Our experiment was conducted with coffee farmers in the Tarrazu region of Costa Rica, which was heavily affected by hurricane Alma in early 2008. This type of extreme events is new to the region, and many farmers were taken by surprise. We purposely conducted our experiment in the region a few months after Alma. In particular, it is hard to explain to farmers that climate change could imply a change in the pattern of extreme events when farmers have lots of prior experience with these types of events, and it is too likely that they will disregard key experimental features. Given that farmers in Tarrazu were well aware of the dangers of an extreme event, but at the same time have little or no priors with respect to the likelihood of future events, we believe this was a good setting to run risk experiments and most importantly, to test farmer's behavior in response to a changing climate.

As expected, we observe high levels of risk aversion, but we do observe farmers making trade offs, and 69% do not adapt if the risk of large income losses is 1%. Hence some farmers still do not adapt, even in the presence of the close memories of an extreme event. Furthermore, we find evidence of a strong effect on adaptation of

ambiguity aversion for the group of farmers who did not adapt at low risk levels.

The implications for policy making of this ambiguity aversion are not straightforward, and there is a lot of discussion particularly with respect to environmental risks, which are frequently associated with unmeasurable uncertainty (see for example Treich 2009; Viscusi, 1998; Viscusi and Hamilton, 1999). In the case of climate change, it is actually realistic to assume that farmers, climate experts, and the government do not know the risk associated to changes in climate.. Viscusi (1998) and Viscuis and Hamilton (1999) argue against "conservatism bias". Treich 2009 discusses two implications of acting on ambiguity aversion. On the one hand, from a purely accounting view, putting concerns for ambiguity aversion on top of risk aversion at the government level might lead to too much protection and too much investment in avoiding certain, unmeasurable, risks. On the other hand, peoples' preferences could favor governmental policies that are attentive of their aversion to ambiguous situations. Our results contribute to this discussion by identifying that both risk and ambiguity aversion seems to be important motives behind adaptation to climate change decisions. We found that around 50% of

those who choose not to adapt to a 5% risk when the risk was known, do adapt if the risk is ambiguous but comparable in expected level. Consequently, ambiguity aversion is an important factor for technology adoption decisions.

What if the government actually knows the true distribution of probabilities of different levels of risk, and farmers exhibit ambiguity aversion? This resembles a situation where people have biased risk perceptions: see for example Olof Johansson-Stenman (2008) for a discussion about perceived and objective risk. From a social efficiency perspective, this might lead, in retrospect, to too much adaptation. In that situation, it could be optimal for the government to provide costly information to reduce the degree of ambiguity among the individuals, insurance programs against worse case scenarios, and improved safety networks, just to mention a few strategies to deal with the extreme negative scenario.

Finally, we also explored the role of communication and monetary incentives (in the form of cost reducing economies of scope arising from full coordination) on the decision to adapt or not to climate change. Monetary incentives for coordination significantly increase the degree of adaptation, but if communication is allowed,

farmers are able to coordinate more frequently in pursuit of the reduced adaptation costs. Notably, if no financial incentives are allowed, communication is irrelevant for the farmer's private decision. Do note that this are experienced farmers who make similar decisions every day, and hence are less likely to be influenced by peers when it comes to how they run their own land.

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Annex 1. Example sheet for farmer A used to explain the experiment

