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The Effect of Risk, Ambiguity, and Coordination on Farmers' Adaptation to Climate Change

A Framed Field Experiment

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Abstract

The risk of losses of income and productive means, due to adverse weather associated with climate change, can differ significantly among farmers sharing a productive landscape. In order to truly understand adaptation patterns to changes in climatic conditions, it is important to learn more about how farmers react to different levels of risk under measurable and unmeasurable uncertainty. Moreover, the costs associated with investments in reduced vulnerability to climatic events are likely to exhibit economies of scope. We explored these issues using a framed field experiment that realistically captured the main characteristics of production and the likely weather-related loses of premium coffee farmers in Tarrazu, Costa Rica. In 2008, the region suffered an extreme, albeit rare, climatic event (tropical storm Alma). In the aftermath of the storm, we expected and found high levels of risk aversion, but also observed farmers making tradeoffs under different risk levels. Although hard to disentangle at first, given the high level of risk aversion, we found that farmers more frequently chose safe options in a setting characterized by unknown risk. Finally, we found that farmers, to a large extent, coordinated their decisions in order to achieve a lower cost of adaptation, and that communication among farmers strongly facilitated coordination.

Key Words: risk aversion, ambiguity aversion, technology adoption, climate change, field experiment

JEL Classification: C93, D81, H41, Q16, Q54

Contents

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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 high costs, but these estimates were criticized for ignoring the possibility of adaptation. The Inter-governmental Panel on Climate Change defined 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."(IPCC 2007, *6*). From a farmer's perspective, climate change can be seen as a technology shock, whose potentially negative effects can be moderated by adapting production function in anticipation of the new reality. The broad literature on agricultural technology adoption in developing countries has focused much attention on explaining why adoption rates have been so low in these countries—for reasons, such as credit constraints, social networks, and tenure insecurity.[1]

For our study, we were interested in three aspects of adaptation to climate change. We first investigated the effect of the level of the risk of income losses due to climate change on farmers' willingness to adapt. Second, we explored whether farmers are ambiguity averse, and if this explains adaptation behavior. Third, we wanted to know if, and to what extent, farmers are able to coordinate their adaptation efforts, and if there are economies of scope in costs.

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[1] See Feder et al. 1985 for a survey.

Risk and risk aversion are likely to be important factors in a 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 roles of risk and risk aversion in the farmer's likelihood of adapting to climate change, we used a framed field experiment (Harrison and List 2004), conducted with small-scale coffee farmers in Costa Rica. In the experiment, farmers were asked to act as if the decisions reflected their actual behavior. The experiment also involved monetary payoffs. The experiment was similar to a standard risk experiment, such as 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 was framed and the values chosen to give the farmers a decision on whether to adapt to climate change or not. We wanted 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, such as global warming, as opposed to the usual climatic variability. Third, climate change might bring about production conditions, particularly for extreme events, that have no historical parallel.

In addition to risk aversion, some authors have argued that ambiguity aversion is a key factor hindering the adoption of new technology. In economics, the interest in unmeasurable uncertainty[2] 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, Moore and Eckel 2006, Slovic and Tversky 1974).[3] By ambiguity aversion, we mean that there is a preference for known risks over unknown risks.[4] In the case of technology adoption,

[2] Knight (1921) distinguished between measurable and unmeasurable uncertainty.

[3] For development of theories of ambiguity aversion, see Gajdos et al. (2008) and Klibanoff et al. (2005), for example.

[4] Klibanoff et al. (2005, *1852*) defined 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…"

the status quo is perceived as a known level of uncertainty, given the agent's 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 technology. 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), who conducted a field experiment with coffee farmers in Peru.

In the context of climate change and technology adoption, both the status quo (no adaptation) and the new state (adaptation) can be characterized by both risk and ambiguity. Climate change is a complex phenomenon, and the estimates of future increases in temperature or the likelihood of extreme events, for example, are very uncertain. The risks associated with not adapting to climate change could therefore be described as unknown or unmeasurable. If farmers are ambiguity averse, they will more likely adapt to climate change when the risk of a disaster is unknown to them, compared to a similar situation with known risk. In our experiment, we tested the effect of unknown risk on adaptation behavior.

There is one other aspect that we investigated: 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 for this is learning from others (Bandeira and Rasul 2006; Besley and Case 1993). Another reason is that the cost and benefit of a technology might actually depend on how many farmers buy and use the technology due to economies of scope—which makes the adaptation decision a public good since the value depends on how many people adopt (Dybvig and Spatt 1983). This opens the door for government intervention, as Dybvig and Spatt (1983) also suggested, and insuring early adopters against the possibility that others do not adopt, for example.

In our experiment, we designed a situation where the cost of technology adoption is lower if everybody (the farmers in our study) in the group adopts. However, players 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 equilibria (see, e.g., 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 are more or less able to communicate with each other in pursuit of reduced costs, as described above. It is important, then, to differentiate between situations where coordination is possible with and without communication. Evidence from other experiments points consistently to the fact that communication leads to increased cooperation and, hence, higher payoffs in common pooled resources and public good settings

(Cardenas et al. 2004; Ledyard 1995; Sally 1995). Moreover, studies also show that the link is not unequivocal because players might react negatively, if they identify noncooperating 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, e.g., Buchan et al. 2006; Bochet et al. 2006; and Bochet and Putterman 2008). Ostrom et al (1994) stressed the latter motive, which likely plays a larger role when the context of the experiment is more complicated, due to group size, task at hand, level of education, and field experiment conditions. In our experiment, we investigated the extent to 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 farmers (or players). We also conducted treatments with and without communication, when there were no strategic reasons for communication, in order to isolate any learning effect.

The rest of the paper is organized as follows. Section 1 provides background information on our sample and the study area where the experiment was conducted. Section 2 introduces the experiment design and procedure. Section 3 presents the results, and section 4 concludes the paper.

1. Description of Sample and Study Area

We conducted our experiment 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 Costa Rica, since membership in a cooperative allows coffee farmers to share the costs of coffee milling and gain better access to market value chains. Still, individual farmers are completely free to make decisions for their land. The Tarrazu region is well known for its premium quality 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 are 75 percent of the farms in the region. Average farm size is 9.8 hectares, but 56 percent of the farms are smaller than 5 hectares. Almost all of the farmers own their land and in 2006 only 16 percent had outstanding loans on their land. This gives a picture of a prosperous region that has an equal distribution of income—although, at the same time, farmers are highly vulnerable to changes in the profits from their land. Because the 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 percent of the farmers have only basic or no education.

In early 2008, tropical storm Alma hit the region with full force. The occurrence of such an extreme weather event in this region is rare because it faces the Pacific Ocean. Based on historical records from 1949, only five extreme weather events have come near the Pacific coast of Costa Rica; Alma came nearest to the country and furthest south (IMN 2008). Only on two occasions have extreme climatic events originating in the Pacific Ocean seriously affected the Central American region, one in 2005 and Alma in 2008. The Tarrazu region was one of the most heavily affected, with approximately 12 percent of all coffee plants destroyed.

In total, 211 farmers participated in our experiment. Table 1 gives descriptive statistics of our sample in the Tarrazu region, based on the 2007 coffee census, which is highly representative of the coffee farmers in this cooperative.

Table 1. Background Statistics of the Sampled Farmers and Regional Census Data

	Population	Sample
Average age in years	42.0	43.3 (15.6)
Male head of household	68%	69%
Education (none; basic; high school; university)	6%; 78%; 8%; 3%	7%; 74%; 14%; 4%
Number of soil conservation practices at farm level	1.77	2.47 (1.42)

Note: Standard errors are In parentheses.
Source: Authors' estimations, based on coffee census (ICAFE 2007)

2. Experiment Design

The experiment had a total of nine rounds to test our hypotheses, as well as order effects. Since we revealed previously hidden information after round 4, we were only able to build in a test for order effects by altering the sequence of the last five rounds. Table 2 shows all nine rounds, and the first column reports the two sequences of treatments.[5] Subjects always played in groups of three, clearly identified as farmer A, B, or C.

[5] Henceforth, we use the first order when referring to the design of the experiment. Notably, we found no significant order effects.

Table 2. Complete Design and Built-in Test for Order Effects

Round	Risk (%) for farmers			Information about neighbors	Gains as a result of coordination	Communication
	Farmer A	***Farmer B***	***Farmer C***			
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	Unknown	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

2.1 Risk and Ambiguity Aversion

Rounds 1–3 are essentially standard risk experiments. Risk levels (1 percent, 5 percent, and 10 percent) were chosen as realistic, based on expert advice, and then validated with pilot studies. In our context, where decisions are made annually, a 1-percent risk level means that farmers might face an extreme weather event once every 100 years. Historical data show that the occurrence of extreme weather events in this region is, indeed, extremely uncommon. We explicitly told the farmers in the study 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 weather event were CRC 500,000 (approximately US$ 1,000)[6] and in the case of an extreme weather event affecting their land, profits would be CRC 50,000 per year. The annual cost of investing in adaptation practices was CRC 200,000. We actually made a point of ensuring that all these numbers corresponded 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 high-productivity, conventional production technology, and that the soil conservation practices

[6] CRC = Costa Rica colones. At the time of the experiment, 1 USD = CRC 500.

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 rounds, 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 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 qualify for payment. Because the risk was not unknown here, this is sometimes called a situation of weak ambiguity.

The main reason that we opted for this approach was to avoid a situation where subjects believed 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 they did. The payoff for a farmer facing the weakly ambiguous situation in our experiment was determined by two known probabilities. The first one related to the risk level that each farmer ultimately faced. In our case, the risk could take any of three values with equal probability. The second one referred to the probabilities of an extreme event, which in our case was 1 percent, 5 percent, and 10 percent. Hence, the expected risk was 5.3 percent. We compared the share of subjects adapting when the risk is known and equal to 5 percent with the share of subjects adapting when the risk is unknown, but the expected value is 5.3 percent. In a strict sense, we should have used other probabilities because the expected value was not exactly 5 percent. However, we wanted to keep the probabilities as simple as possible. Table 3 summarizes the design of the first four rounds.

In round 5, all farmers faced a risk level of 1 percent. This round was designed to introduce 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).

Table 3. Risk and Ambiguity Treatments

Risk levels*	Adapts (safe option)	Does 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 is neutral

* Farmers faced all risk levels in one of the first 3 rounds.

2.2 Gains from Coordination and Communication

Finally, rounds 6–9 were designed to test the effect of potential gains of coordinating adaptation and the role of communication in increasing the likelihood of coordination. In all these four rounds, farmers A, B, and C faced risk levels of 1 percent, 5 percent, and 10 percent, 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 weather events could affect one farmer and not the others, we told each group of three farmers that "if the three of you decide to adapt, the cost of adaptation is 100,000 colones. If fewer than three of you decide to adapt, then the cost of adaptation is the same as before, that is 200,000 colones." Note that at this stage we still did not allow any interaction between the players, so that rounds 6 and 7 differed only in the potentially-lower adaptation costs.

Round 8 was identical to round 7, but now we finally permitted interaction between the three group members, which allowed us to test for the role of communication when there were gains to coordination. So, in rounds 6 and 9, there were no gains to coordination and, hence, no strategic reason for changing behavior in round 9 as a result of communication. Our two-by-two design let us isolate the use of communication in round 9 as a way of better understanding how communication was used as a tool for coordination.

2.3 Experimental Procedure

The cooperative in Tarrazu organizes yearly meetings of all its members from 11 villages. We used those meetings to invite farmers to participate in our experiments (called workshops). The invitation was made 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 hoped to learn from their experience with a changing climate, and that they would have the opportunity to participate in a set of activities where they could earn some money, depending on their decisions as farmers. A detachable slip was to be returned to us, with name, telephone number, and location filled in by each farmer. We followed this invitation up with phone calls to confirm their interest in participating. This strategy was not different from the one used by the cooperative to announce 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 escorted 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 took away the chairs available to subjects, and latecomers were allowed to be 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 would last two hours and reassured them about the confidentially of their individual responses. At this time, we allowed people to leave if they chose, but very few took this option and only because they did not have the time. We also requested that there 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 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 weather events, could negatively affect their profitability due to increased erosion, reduced soil fertility, and in the worst case extreme losses, similar to those experienced from 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 100 red and white dots equivalent to 0 percent, 1 percent, 5 percent, and 10 percent. These visual representations of risk were available the entire time. A rotating drum (tombola) with 100 red and white balls was also used, mainly to correlate the risk charts to the number of balls and eventually to our payment strategy. Throughout this presentation, we stressed that risk could differ between neighbors and that an extreme weather event could occur independently to all subjects. Several trial runs were conducted until there were no more questions.

The actual experiment started with an explanation of the setting. We told the subjects 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 (one for each round), and an exit survey. The pages were stapled together, such that the farmers could not browse forward in the booklet. We used the example sheet in the appendix 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 would be determined according to their risk.

Finally, we explained the payment method, which is quite standard for this type of experiment. First, we told them that one of the nine rounds would be randomly selected for a real payment.[7] Also, given our budget limitations, we explained that an exchange rate of 1:1000 would be used, but asked them to focus on the per-hectare payoffs that corresponded with their reality as coffee producers. (Our converted payment exceeded one day's salary on a coffee farm, clearly enough to be attractive and real.) Before starting the experiment, we conducted several example payments to show how we would pay, as well as 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.

In box 1 is the actual translated script read to the farmers for round 1. The decision sheets were similar to the example in the appendix, so the script served to guide subjects through the details of the round. We made small variations in this script as needed for the rest of the rounds.

[7] Later in the experiment, we explained that, for round 4 with ambiguous risk, a further random selection of risk was needed.

Box 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 on your sheet. As a visual aid, you can see in this slide all the possible risk levels you can face. [SHOW SLIDE WITH 3 RISK LEVELS]

- If you choose to invest in adaptation, your profit is [₡300,000], independent 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 on your sheet.

You do not know the level of risk of the 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 some will have 10 red balls in the tombola. Please check your level of risk carefully. 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 situation. Please do not talk to each other. Do you have any questions? [WAIT; ANSWER QUESTIONS.] Please mark your decision in the corresponding box.

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3. Results

A total of 211 observations were gathered in the 11 workshops. The following results explore our two main research questions: 1) what is the risk and ambiguity aversion, and 2) to what extent do farmers coordinate their adaptation decision to reduce costs and what is the importance of communication? For the first question, we used individual observations, and for the second, we observed and noted the group decisions.

3.1 Risk and Ambiguity Aversion

We began by looking at how farmers behave with various levels of risk of having their crops destroyed by extreme weather associated with 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 adapted at a low, but not at a high, level of risk. In total, 17 percent of the farmers were inconsistent. We removed the inconsistent farmers' answers and were left with 175 observations. Table 4 presents the number and share of farmers adapting and not adapting at the three different levels of risks.

As expected, the share of farmers adapting increased as the level of risk increased, and the differences in shares were 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 payoff) was higher than 3.4 for 31 percent of the subjects, and the median degree of risk aversion was between 2.25 and 3.4. Consequently, the farmers were 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 weather event as dramatic as tropical storm Alma, we think it is noteworthy that 69 percent of all farmers did not adapt at a risk of 1 percent. When the risk level increased to 10 percent, only 5 percent of the subjects did not adapt.

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	Does not adapt	Adapts
1%	3.4	120 (69%)	55 (31%)
5%	2.25	40 (23%)	135 (77%)
10%	1.75	9 (5%)	166 (95%)

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

We next investigated whether the farmers were ambiguity averse. We compared the shares of subjects 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	Does not adapt	Adapts
Known risk, 5%	40 (23%)	135 (77%)
Unknown risk (between 1 and 10%)	38 (26%)	137 (74%)

Note: 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.[8] Consequently, looking at the aggregate data, there is no evidence of ambiguity aversion. One problem with our test is the high proportion of people adapting, even when the risk is 5 percent. Subjects already adapting when the risk is 5 percent could be adapting when the risk is unknown, but with an expected value of 5.3 percent, even if

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

they were not ambiguity averse. Table 6 shows the tests for the group of participants who only adapted when the risk was 10 percent or did not adapt at all (40 out of 175 farmers).

Table 6. Subsample of Farmers Not Adapting and Adapting

Farmers not adapting and adapting when the risk is known and 5%, and when the risk is unknown, for a subsample of subjects that never adapts when the risk is known or only adapts when the risk is known and equal to 10%		
Risk of crops destroyed	***Does not adapt***	***Adapts***
Known risk, 5%	40 (100%)	0 (0%)
Unknown risk (between 1 and 10%)	18 (45%)	22 (55%)

Note: P-value, chi-square test of difference in distribution between known and unknown risk = 0.001.

By construction of the test, none of these farmers adapted when the risk is 5 percent. However, when they faced the ambiguous situation (with an expected risk of 5.33 percent), 55 percent 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, put differently, the fact that the risk is unknown induces more adaptation than the corresponding situation with known risk.

Finally, we estimated a logit model, where the dependent variable was equal to 1 if the farmer decides to adapt. We did this in order to explore the effect of socioeconomic characteristics, as reported in the exit survey completed by all subjects. Treatment effects were included as dummy variables. (We used 5 percent as the baseline risk level.) The results are shown in table 7, where standard errors have been corrected by clustering.

Table 7. Logit Results Using the 5% Risk Level as Baseline

	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 implemented (2.46)	0.032	0.073
Losses due to tropical storm Alma	= 0 if no losses; 2 if losses larger than CRC 250,000 per hectare; 1 otherwise (1.81)	-0.023	0.485
Number of subjects; number of observations		171; 700	
Pseudo-R2		0.252	

Note: Dependent variable is equal to 1 if farmer adapts.

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

3.2 The Role of Communication and Cost-Saving Coordination

In the last four rounds of the experiment, subjects knew their own risk and the risk of the two other group members. The first difference between the rounds was whether subjects were allowed to communicate or not. The second difference was whether the subjects had an incentive to coordinate on adaptation or not. As explained in section 2.2, farmers were told that if all group members decide to adapt, adaptation costs would be reduced by 50 percent. This is indeed a realistic situation because 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 then focused on the decision at the group level and not the individual farmer. For this reason, we removed groups with fewer than 3 farmers, resulting in a total of 68 groups. Table 8 summarizes the outcomes in the groups for the four treatments.

We made two interesting comparisons. First, we tested whether the whole distribution of the number of subject adapting in a group was different for two treatments (Chi-square test). Second, we tested whether the share of groups actually achieving full coordination in adaptation (and hence a possible cost reduction), i.e., where all three players adapt, was different for the alternative treatments (proportion test).

Table 8. Number of Groups with Different Number of Subjects Adapting in Each Treatment*

Number of subjects adapting	Treatment 6	Treatment 7	Treatment 8	Treatment 9
	No gains with coordination and no communication	***Gains with coordination and no communication***	***Gains with coordination and communication***	***No gains with coordination and 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%)

* Treatments 6–9 were played in different orders to test for order effects, but we found no significant order effects. Aggregate results are reported in the table.

To begin with, look at treatments 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 adapted and thus got a reduced adaptation cost, but there is no significant difference in the overall distribution (Chi square test p-value = 0.111). So, farmers were able to coordinate only to a limited extent, if they could not communicate with each other, and the pattern of "failed" coordination efforts was not different in both cases. The question is what happens if we allowed communication, as in treatment 8 (compared to 7). Communication in the pursuit of reduced adaptation costs achieved a significant change in the distribution of responses (Chi-square test p-value = 0.053) and, in 69 percent of the groups, all subjects adapted, 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 were allowed and, if coordination was successful, would lead to reduced costs. In round 9, communication was also allowed, but was inconsequential in terms of costs. The increase in the number of groups where everybody adapted was high and significant when cost reductions were at stake, compared with no gains from coordination (proportion test p-value = 0.001). The difference in distributions was also significant, using a chi-square test (p-value = 0.004). In order to test the effect of communication alone, we compared treatments 6 and 9, which were 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 had no effect on a 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.

4. Discussion

We conducted our experiment with coffee farmers in the Tarrazu region of Costa Rica, which was heavily affected by tropical storm Alma in early 2008. This type of extreme weather event 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 was hard to explain to farmers that climate change can imply a change in the pattern of extreme weather events, due to the fact that the farmers have lots of prior experience with the expected types of events, and it was all too likely that they would disregard key features of the experiment. Given that farmers in Tarrazu were well aware of the dangers of an extreme weather event and at the same time had little or no prior expectation of the likelihood of future events, we believed this was a good setting to run risk experiments and, most important, test farmers' behavior in response to a changing climate.

As expected, we observed high levels of risk aversion, but we did not observe farmers making tradeoffs: 69 percent did not adapt when the risk of large income losses (in the study) was 1 percent. Some farmers still did not adapt, even with the close memories of an actual extreme event. Furthermore, we found evidence of a strong effect on adaptation from ambiguity aversion for the group of farmers who did not adapt at low risk levels.

The implications for policymaking with this ambiguity aversion are not straightforward. There is a lot of discussion, particularly with respect to environmental risks that 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 with changes in climate. Viscusi (1998) and Viscusi and Hamilton (1999) argued against “conservatism bias.” Treich 2009 discussed two implications of acting on ambiguity aversion. On 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 pay attention to their aversion to ambiguous situations. Our results contribute to this discussion by identifying that both risk and ambiguity aversion seem to be important motives behind decisions to adapt to climate change. We found that around 50 percent of our subjects, who chose not to adapt to a 5 percent risk when the risk was known, did adapt if the risk was ambiguous, but comparable to expected levels. 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 what if farmers exhibit ambiguity aversion? This resembles a situation where people have biased risk perceptions.[9] From a social efficiency perspective, this might lead, in retrospect, to too much adaptation. In this 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 for dealing with an extremely 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 adapt to climate change. Monetary incentives for coordination significantly increased the degree of adaptation. However, when communication was allowed, farmers were able to coordinate more frequently in pursuit of the reduced adaptation costs. Notably, if no financial incentives are allowed, communication is irrelevant to the farmer’s private decision. Note, too, that our subjects were 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.

[9] See, for example, Johansson-Stenman 2008 for a discussion about perceived and objective risk.

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Appendix. Example Sheet for Farmer A, Used to Explain the Experiment