Environment for Development

Discussion Paper Series Sept. 2009; Revised Nov. 2010 ■ EfD DP 09-18-REV

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A Framed Field Experiment

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Environment for Development

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Farmers' Adaptation to Climate Change: A Framed Field Experiment

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Abstract

The risk of losing income and productive means due to adverse weather can differ significantly among farmers sharing a productive landscape and is, of course, hard to estimate or even "guesstimate" empirically. Moreover, the costs associated with investments in adaptation to climate are likely to exhibit economies of scope. We explore the implications of these characteristics on Costa Rican coffee farmers' decisions to adapt to climate change, using a framed field experiment. Despite having a baseline of high levels of risk aversion, we still found that farmers more frequently chose the safe options when the setting is characterized by unknown risk (that is, poor or unreliable risk information). Second, we found that farmers, to a large extent, coordinated their decisions to secure a lower adaptation cost and that communication among farmers strongly facilitated coordination.

Key Words: risk, ambiguity, 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 (e.g., Adams 1989; Mendelsohn et al. 1994; Schlenker et al. 2005). Technological innovations, changing patterns of land use, and changes in ecosystem dynamics can either lessen or exacerbate the effect of climate change on agriculture (e.g., Antle 1995; Reilly 1995.) From a farmer's perspective, climate change—whether it comes as slow changes in temperature or precipitation, changes in seasonal weather patterns, or more frequent extreme events (droughts or floods)—can be seen as a technology shock, whose potentially negative effects can be moderated by adapting[1] the production function. Farmers can adapt tactically (changing input use and timing planting and harvesting) and/or strategically (e.g., selecting different crop varieties, diversifying crops, and/or purchasing crop insurance) to climate change (Bradshaw et al. 2004).

Global climate analysis signals Central America as one of the most affected tropical regions in the world, in terms of higher temperatures (Aguilar et al. 2005; 2006), a clear "drying signal" (Rauscher et al. 2008), and increased variability (Giorgi 2006). Most important, global studies predict more intense rain and more widespread droughts (Aguilar et al. 2005; Sheffield 2008; Magrin et al. 2007). In a recent report for Central America (Curry et al. 2008), a predicted 0.6°C increase in sea surface temperature is associated with between 0 and 1 additional tropical cyclones per year and 10–26 percent increase in damage.

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The authors thank Olof Johansson-Stenman and Maria Claudia Lopez for their valuable comments. Financial support from Sida (Swedish International Development Cooperation Agency) to the Environmental Economics Unit at University of Gothenburg and the Environment for Development Center at CATIE is gratefully acknowledged.

[1] 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).

This article starts by constructing a standard baseline of farmers' adaptation behavior and risk aversion under known risk, and then considers our two research questions. First, we tested whether farmers are ambiguity averse, and whether this explains adaptation behavior. Second, we explored if, and to what extent, farmers are able to coordinate their adaptation efforts in pursuit of economies of scope in adaptation costs.

We used a framed field experiment (Harrison and List 2004), conducted with small-scale coffee farmers in Costa Rica, in which farmers were asked to act as if their decisions for the situations in the experiment reflected their actual behavior. The experiment also involved monetary payoffs. The baseline for the experiment was a standard risk experiment, such as Holt and Laury (2002), to which a realistic frame and treatments to explore ambiguity and cooperation were introduced. 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 values were chosen to give the farmers a familiar decision on whether to adapt to climate change, associated in this case with increased risk of extreme events and income losses.

There are several reasons for using a framed field experiment instead of actual production data (e.g., Antle 1987; Antle 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 this coffee-producing region.

In addition to risk aversion, some authors have argued that ambiguity aversion is a key factor hindering the adoption of new technologies. 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 generally ambiguity averse (e.g., Fox and Tversky 1995; Moore and Eckel 2006; Slovic and Tversky 1974).[3] By ambiguity aversion, we

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

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

mean that there is a preference for known over unknown risks.[4] In the case of technology adoption, the status quo is perceived to have 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. 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 (IPCC 2007). 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 explored the relevance of reliable risk information for adaptation decisions.[5]

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, either due to learning from others (Bandeira and Rasul 2006; Besley and Case 1993) or due to economies of scope. This opens the door for government intervention, as Dybvig and Spatt (1983) also suggested, aimed at insuring early adopters against the possibility that others do not follow, for example.

In our experiment, we designed a situation where the cost of technology adoption is lower if everybody in the group (the farmers in our study) adopts. However, farmers face different risks and have different risk preferences. This means that the decision can be viewed as a coordination game, where there could be multiple equilibria (e.g., Ochs 1995; and Cooper et al. 1999).

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[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."

[5] Viscusi and Chesson (1999) found that subjects in their experiment moved from ambiguity aversion when the risk of a loss is small (*fear effect*) to ambiguity-seeking behavior when the probabilities of a loss are large (*hope effects*). Our design includes probabilities that are well within the range of small probabilities discussed in their article.

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 in public good settings even with heterogeneous subjects (Cardenas et al. 2004; Hackett et al., 1994; Ledyard 1995; Sally 1995). Moreover, studies also show that the link is not unequivocal because players might react negatively, if they identify noncooperative behavior in the course of group discussions.

Some explanations for the effect of communication on group decisions include persuasion, verbal promises, creation of a group identity that favors cooperation, and improved understanding of the game. (e.g., Buchan et al. 2006; Bochet et al. 2006; Ostrom et al. 1994; Bochet and Putterman 2008). In our experiment, we investigated the extent to which farmers reduce their vulnerability to extreme events when there are economies of scope in the adaptation cost. 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 article 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 Tarrazu region of Costa Rica. All coffee producers are organized in a cooperative, a common type of organization in Costa Rica, which provided our sampling frame. Still, individual farmers are completely free to make decisions for their land. This 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. Coffee plantations make up 76 percent of all the farms in the region. The average coffee farm size is 10.3 hectares, but 64 percent of the farms are smaller than 5 hectares. Almost all of the farmers own their land and, in 2006, only 10 percent had outstanding loans on their land. This gives a picture of a prosperous region that has an equal distribution of income. At the same time, however, 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.

Changes in climate mean reduced coffee production, given the plants' sensitivity to extreme temperatures (warm and cold) and humidity (both excessive moisture and drought). Wind and heavy rain can also bring severe losses if they occur during the flowering period and if they physically damage the plant (Tucker et al. 2010).

In early 2008, tropical storm Alma hit the region with full force. The occurrence of such extreme weather events 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 closest 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	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. Experimental Design

The experiment used a total of nine rounds to test our hypotheses and 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.[6] Subjects always played in groups of three, clearly identified as farmer A, B, or C.

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

Rounds 1–3 built our baseline and are essentially a standard risk experiment. 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 (10 percent) risk level means that farmers might experience large losses due to extreme weather event once (10 times) every 100 years. Historical data show that the occurrence of extreme weather events in the Tarrazu region is, indeed, exceedingly uncommon and real risk is likely below 1 percent. The whole of the Mesoamerican region (Mexico to Panamá) faces one tropical cyclone (that makes land fall) per year, although pessimistic predictions double that rate (Curry et al. 2008). Hence, adding higher levels of risk would result in reduced realism.[7] We explicitly told the farmers in the study to consider their group members as neighbors, but at this stage we asked for no interaction between them. We did not give them any information about the risk level of the other group members.

[6] Henceforth, we use the first order when referring to the design of the experiment. Round 5 was introduced only to strengthen our tests for order effects. Notably, we found no significant order effects using a chi-square test (p-value = 0.828).

[7] In addition, our experimental results show most farmers adapt at a 10% risk level, so higher levels of risk would add little to our capacity to estimate risk aversion.

Farmers were also told that their annual profits in the case of no extreme weather event were CRC 500,000 (approximately US$ 1,000),[8] 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 highly-productive, conventional production technology, and that 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 on these practices, which include changing the intensification of production (e.g., adding shade trees) to accommodate environmental variations, changing planting locations to areas on the farm less exposed to wind or crevasses, and improving irrigation for droughts or water management for excessive rainfall, among others.

2.1 Ambiguity Aversion

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. 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.

Because the payoff for a farmer facing the ambiguous situation in our experiment was determined by two known probabilities, one to select the risk level and the second to define the outcome, this is sometimes called a situation of weak ambiguity, in which expected risk is 5.3 percent. We wanted to keep the probabilities as simple as possible and therefore the expected risk was not exactly the same as in the round with known risk equal to 5 percent. Table 3 summarizes the design of the first four rounds and the last column shows the corresponding degree of relative risk aversion. This is the same measure reported by Holt and Laury (2002), and it assumes a constant relative risk-aversion utility function that is only a function of the payoff of the experiment.

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[8] At the time of the experiment, US$ 1 = CRC 500. CRC = Costa Rica colones.

Table 3. Baseline Risk and Ambiguity Treatment

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 three rounds.

2.2 Gains from Coordination and Communication

Finally, rounds 6–9 were designed to test the effect of potential gains of coordinating adaptation efforts 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 of them. 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, who come 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. The invitation had a detachable slip to be returned to us, with name, telephone number, and location filled in by each farmer. We followed up this invitation with phone calls to confirm their interest in participating. This process was not very different from the way the cooperative announces its 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 researchers conducted the experiment. Farmers were escorted into the workshop 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 any remaining chairs, 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 severe losses, similar to those experienced from tropical storm Alma. This was obviously 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 happen 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 appendix 1 to explain the basics of the nine 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, at the end of the experiment, one of the nine rounds would be randomly selected for a real payment.[9] Also, given our budget limitations, we explained that an exchange rate of 1:1,000 would be used, but asked them to focus on the per-hectare payoffs that corresponded with their reality as coffee producers. Our converted payment still exceeded one day's salary on a coffee farm. Before starting the experiment, we conducted several example payments to show how we would pay, as well as to make it very clear that they were playing for real money.

To reduce biases in data to be collected in several workshops, the field staff had a very detailed script to follow. A translated example of the script for round 1 is provided in appendix 2. The decision sheets were similar to the example in appendix 1, 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.

3. Results

A total of 211 observations were gathered in the 11 workshops held. The following results explore our two main research questions: 1) is there a difference in observed adaptation when farmers face unknown as opposed to known risk; and 2) to what extent do farmers coordinate their adaptation decision to reduce costs and what is the importance of

[9] As noted before, if round 4 was selected for payment, we would make an additional random draw to select the risk level.

communication? For the first question, we use individual observations, and for the second, we use group decisions.

We began by building a standard baseline of farmers' behavior when faced with varying levels of risk of having their crops destroyed by extreme weather. 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.[10] 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.

Table 4. Number of Farmers Not Adapting and Adapting under Various Levels of Risk

Risk levels	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.

As expected, the share of farmers adapting rises 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 payoff) is higher than 3.4 for 31 percent 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 weather event as dramatic as tropical storm Alma, we think it is noteworthy that 69 percent of all farmers did not adapt at a 1 percent risk, confessedly similar to the status quo. When the risk level increased to 10 percent, only 5 percent of the subjects did not adapt.

[10] As expected, the share of inconsistent responses is somewhat higher than what is typically found in laboratory experiments with students. For example, in Holt and Laury (2002), the fraction of inconsistent choices ranged 5%–13%, depending upon treatment. However, given the more complicated nature of the game, the more diversified subject pool, and the low education level of our sample, the observed share is acceptable.

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. The results are shown in the table in appendix 3. From the subject characteristics, we found that males and older farmers had a significantly higher probability of adapting, whereas education had no significant effect on behavior in the experiment. Subjects with big coffee farms 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 livelihoods.

3.1 Unknown Risk and Ambiguity Aversion

We now turn to the first research question regarding the difference in adaptation behavior when farmers face unknown risk as opposed to risk. Since we only included one round with unknown risk—where the expected risk was 5.3 percent—what we can say about the farmers' preferences toward ambiguity depends on their risk preferences. In table 5, we report adaptation behavior in the round with unknown risk for farmers with different risk preferences.

Table 5. Number of Farmers Not Adapting and Adapting When Risk Is Unknown

Behavior when risk is known		**Behavior of set of farmers when risk is unknown**	
Sets of farmers	**No. of obs.**	**Does not adapt**	**Adapts**
Adapts when risk is 1%	55	9[a]	46[b]
Adapts when risk is 5%, but not when risk is 1%	80	11[c]	69[b]
Adapts when risk is 10%, but not when risk is 5%	31	10[e]	21[d]
Does not adapt even when risk is 10%	9	8[b]	1[a]

[a] Inconsistent response
[b] Ambiguity loving, neutral or averse
[c] Ambiguity loving
[d] Ambiguity averse
[e] Ambiguity loving or neutral

Depending on the change in farmers' behavior in the rounds where risk was known versus unknown, we can classify some of the farmers as either ambiguity neutral, averse, or loving. For some farmers, we do not have sufficient information. For example, the 55 farmers who adapted when the risk was 1 percent and known should also adapt when risk is unknown, but equal or larger than 1 percent, regardless whether they are ambiguity averse, neutral, or loving. As described in the table, some farmers were inconsistent. Our focus here is on the set of farmers definitely classified as either ambiguity averse or ambiguity loving. These are the ones that adapted when the risk is 10 percent, but not when the risk is 5 percent (31 out of 175 farmers). Of these, 21 chose to adapt when they faced an ambiguous situation (with an expected risk of 5.33 percent), meaning that they are ambiguity averse. The remaining 10 farmers were either ambiguity neutral or loving. Using a chi-square test, the difference in the share of farmers adapting is highly significant (p-value = 0.000), 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.

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 a previous section, 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 now turn to the decision at the group level, where we removed groups with fewer than three farmers, resulting in a total of 68 groups. Table 6 summarizes the outcomes in the groups for the four treatments.

Table 6. 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%)

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

We can make two interesting comparisons. First, we tested whether the whole distribution of the number of subjects adapting in a group is different for two treatments, using a chi-square test. Second, we tested whether the share of groups actually achieving full coordination in adaptation (i.e., where all three players adapt) were different for the alternative treatments, using a proportion test.

We first looked 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 was a significant increase (proportion test p-value = 0.055) in the share of groups where all adapted and, hence, 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 allow communication, as in treatment 8 (compared to 7).

Communication in the pursuit of reduced adaptation costs produced 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 benefitting from coordination. This share was 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 concrete 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. Conclusion

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. It is hard to explain to farmers that climate change can imply a change in the pattern of extreme weather events when farmers have a lot 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 expectations of the likelihood of future events, we believed this was a good setting to run risk-related experiments and, most importantly, test farmers' behavior in response to key features of a changing climate and adaptation response.

As expected, we observed high levels of risk aversion, but we also observed farmers making tradeoffs in the experiment. Furthermore, we found some evidence of 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 in the literature, particularly with respect to environmental risks that are frequently associated with unmeasurable uncertainty (e.g., 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. 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 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 ambiguity aversion seems to be an important motive 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. Contrary to the discussion in the technology adoption literature, we found that ambiguity aversion is an important factor favoring the adoption of technology that would help farmers cope with climate change.

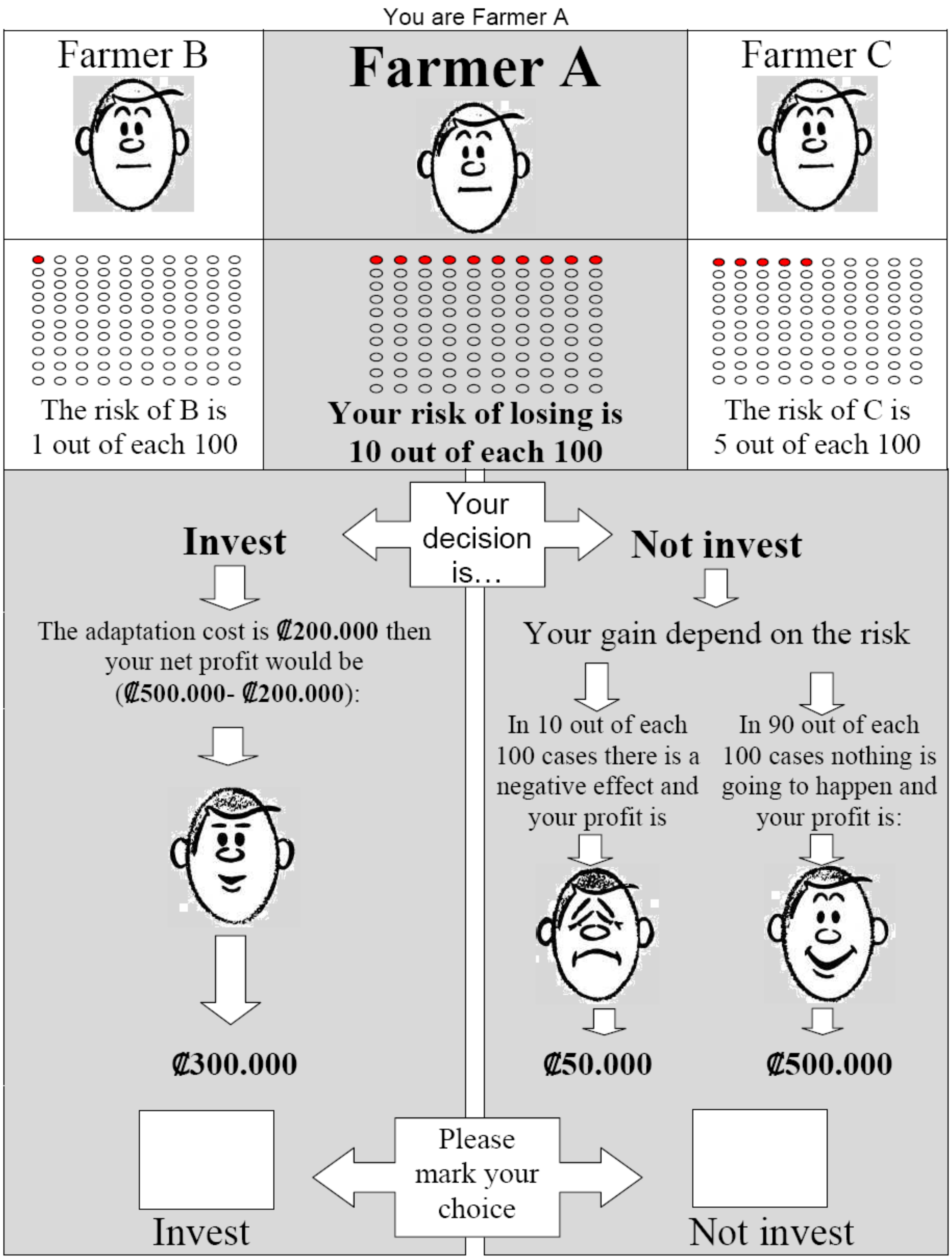
What if the government actually knows the true distribution of probabilities of different levels of risk and farmers exhibit ambiguity aversion? This resembles a situation where people have biased risk perceptions. (See, e.g., Johansson-Stenman 2008 for a discussion about perceived and objective risk.) From a social efficiency perspective, this might lead, in retrospect, to too much adaptation. In this situation, it could be optimal for the government to provide (costly) information to reduce the degree of ambiguity of 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 motives are allowed, communication is irrelevant to a 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.

These results provide a strong mandate to producer and local organizations, which can play a key facilitating role in sorting out the most promising technologies, the cheapest providers of those technologies, and the securement of more readily available access to technical assistance. According to our results, farmers will converge on these organizations in pursuit of reliable risk estimates and economies of scope in adaptation costs.

Appendices

Appendix 1. Example Sheet for Farmer A, Used to Explain the Experiment



Appendix 2. Translated Script for Round 1

(Square brackets are not read aloud.)

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 three risk levels]*

If you choose to invest in adaptation, your profit is X colones, 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.

Appendix 3. Results

Logit Results Using the 5% Risk Level as Baseline

	Description (mean)	Marginal effect	P-value
Treatment characteristics			
Low risk (1%)	= 1 if low risk (0.33)	-0.427	0.000
High risk (10%)	= 1 if low risk (0.33)	0.271	0.000
Subject characteristics			
Male	= 1 if subject is male (0.71)	0.125	0.077
Age	Age in years (43.33)	0.003	0.052
Big coffee farm	= 1 if number of hectares > 5 (0.27)	-0.146	0.037
Previous investment in soil conservation	Number of soil conservation measures implemented (2.46)	0.029	0.163
Losses due to tropical storm Alma	= 0 if no losses; 2 if losses larger than CRC 250,000 per hectare; 1 otherwise (1.81)	-0.009	0.817
Number of subjects; number of observations		175; 525	
Pseudo-R2		0.252	

Note: Standard errors are corrected for clustering. Dependent variable is equal to 1 if farmer adapts.

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