Ambiguity Aversion and Portfolio Choice in Small-Scale Peruvian Farming

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Abstract:
We investigate the role that ambiguity aversion plays in subsistence farmers' diversification strategies. Our model hypothesizes that both risk and ambiguity aversion cause less diversification by farmers from safe options. The model also demonstrates that ignoring ambiguity aversion overstates the importance of risk aversion. We use experimental measures of risk and ambiguity aversion combined with survey data on farm decisions from a sample of subsistence farmers from rural Peru. We find that risk aversion reduces the likelihood that farmers diversify away from safe crops and that ambiguity aversion reduces the probability they diversify among crop varieties.
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1 Introduction

Agricultural production is risky: a farmer's output depends on weather, price and yield fluctuations. If markets are perfect and complete, these risks should not matter for the farmer's standard of living if she is able to perfectly contend with risk by insuring against negative shocks to her production. However, subsistence farmers in developing countries often face substantial constraints in their ability to contend, *ex-post*, with risk. Formal credit and insurance markets are thin where informational asymmetries are high, collateral is low, and informal mechanisms are often unstable. In response to the absence of *ex-post* risk management mechanisms, subsistence farmers appeal to *ex-ante* mechanisms to reduce their exposure to risk: for instance, they plant crops and seed varieties with low expected yield but low yield variance, shy from adopting new but unknown technologies, and diversify their production portfolios to minimize their exposure to idiosyncratic risk.[1]

In this paper, we consider one important *ex-ante* risk coping mechanism available to subsistence farmers: crop and varietal diversification. Much of the literature has focused on the role of risk preferences. By diversifying across different crops and different crop varieties, farmers can self-insure against idiosyncratic risk. However, because substantial empirical evidence suggests that subsistence farmers are risk averse (e.g. Binswanger (1980) and Dillon and Scandizzo (1978)), they are less likely to diversify away from the safe crop or crop variety. Research has shown that farmers are thus less likely to adopt new and possibly high-yielding varieties which they view as risky (Feder et al., 1985).

We argue that in addition to risk aversion, farmers' decision-making is also influenced by their aversion to ambiguity. Ambiguity aversion relates to the aversion towards ambiguous outcomes; specifically, the uncertainty regarding the probability distribution of outcomes. Ambiguity aversion is different than risk aversion, because risk aversion only concerns the

[1] See Morduch (1995) and Alderman and Paxson (2002) for reviews of the literature on income and consumption smoothing among the poor and the mechanisms they have for coping with risk.

uncertainty regarding the realization of the outcome. Because both the realization of the outcome as well as the probability distribution of the outcome may be unknown, it is important to distinguish the two different concepts. Since farmers must choose among many different crops and varieties and since the probability distributions over yields are not always known, especially in the case of new varieties generated by the Green or Gene Revolutions, ambiguity aversion may be particularly important in their diversification decisions.

The importance of ambiguity aversion in portfolio choice decisions is not new (e.g. Klibanoff et al. (2007)). However, there is little evidence of its importance in portfolio choice decisions of small-scale or subsistence farmers from developing countries. Determining its contribution to how poor farmers contend with risk is thus an important line of research. If risk aversion matters, there is little that policy makers can do other than to help improve *ex-post* risk coping mechanisms by helping farmers access formal credit and insurance markets, which is difficult to do in poor countries. However, if ambiguity aversion matters, then policy makers can help via *ex-ante* mechanisms in which farmers resolve the uncertainty through education, agricultural research, technical assistance or agricultural extension services. Because the policy prescriptions for the two cases is so different, knowing the relative importance of the two behavioural effects is key for guiding policy geared towards alleviating the negative effects of risk on the rural poor.

We develop a model of diversification which takes into consideration both risk and ambiguity aversion. We then test the prediction of our model in rural Peru, where agricultural risk is high and *ex-post* risk coping mechanisms (formal credit and insurance markets) are thin and where 65% of the population lives below the poverty line (INEI, 2008). In 2006, we conducted laboratory experiments in the field in two coastal and five mountain communities to measure farmers' risk and ambiguity preferences. In addition, we collected socio-economic survey data which, combined with our experimental results, allow us to uniquely explore the roles of risk and ambiguity aversion on farmers' decision-making.

2 A model of diversification

The model of diversification follows Dercon (1996) and Klibanoff et al (2007). We are interested in understanding how portfolio choice is affected by risk and ambiguity aversion. Though our model describes crop diversification, it is generalizable to other contexts: indeed, we consider different crop varieties as well as different crops in the empirical analysis.

Consider a farmer who must choose how much of the risky crop and how much of the safe crop to plant. Consider that there are two states of the world $i = \{1, 2\}$, where state 1 is the good state (e.g. high yield) and state 2 is the bad state (e.g. low yield). State 1 occurs with probability p and so state 2 occurs with probability $(1-p)$. Let x_s be the output (payoff) from planting the safe crop, which is invariant to the state of the world. Let x_{ri} be the output (payoff) from planting the risky crop in state i such that:

$$x_{r2} < x_s < x_{r1} \tag{1}$$

The farmer must choose what proportion α of her wealth (or land), normalized to 1, to invest in the risky crop to maximize her expected utility, where ρ is the coefficient of relative risk aversion, and τ is the coefficient of ambiguity aversion. We model expected utility in a risky environment with a CRRA utility function:

$$u(x) = \begin{cases} \frac{1}{1-\rho} x^{1-\rho} & \text{if } \rho \neq 1 \\ \log(x) & \text{if } \rho = 1 \end{cases} \tag{2}$$

Following Klibanoff et al. (2007), we consider a constant absolute ambiguity aversion (CAAA) utility function:

$$\phi(x) = \begin{cases} \frac{1-e^{-\tau x}}{1-e^{-\tau}} & \text{if } \tau > 0 \\ x & \text{if } \tau = 0 \end{cases} \tag{3}$$

The general expected utility function which considers a diversified portfolio under both risk and ambiguity can thus be represented using both (2) and (3):

$$EV(x) = \begin{cases} \int_{\underline{p}}^{\overline{p}} \frac{1}{1-e^{-\tau}} \left[1 - e^{-\tau\{pu(\alpha x_{r1}+(1-\alpha)x_s)+(1-p)u(\alpha x_{r2}+(1-\alpha)x_s)\}}\right] dp & \text{if } \tau > 0 \\ \int_{\underline{p}}^{\overline{p}} [pu(\alpha x_{r1} + (1-\alpha)x_s) + (1-p)u(\alpha x_{r2} + (1-\alpha)x_s)]dp & \text{if } \tau = 0 \end{cases} \quad (4)$$

For intuition behind the expected utility expression in (4), consider the farmer who does not know the probability with which the good state will occur. Then she takes the expected value of her utility over all possible probabilities. She may have priors about this probability, such that $\underline{p} < p < \overline{p}$. As a special case, $\underline{p} = 0$ and $\overline{p} = 1$, such that ambiguity is at its greatest. As the ambiguity resolves, the interval defined by $\underline{p}$ and $\overline{p}$ narrows.

Why distinguish between risky and ambiguous crops for farmers? Imagine a farmer who must decide which crops to plant in the next season. While she may know fairly well the probabilities with which a particular crop will have a high or a low yield, she generally does not know *ex ante* with certainty whether the high or the low yield will realize. This is the risky case, because the uncertainty concerns only which state of the world will realize in the future. However, it is also possible, say in the case of a new crop, that she also doesn't know the probability with which the crop will have a high yield. In this case, the uncertainty is about the yield probabilities, in addition to the uncertainty about which state of the world will realize. This is the ambiguity case. Suppose that she learns about the yield distribution of the new crop, either through her experience, the experience of others, or agricultural extension services, then the ambiguity can be resolved. If there is no ambiguity, e.g. p is known, then the objective function does not take the integral form as in (4). In this case, x_r is a risky crop because it pays x_{r1} in the good state of the world with known probability p, but $x_{r2} < x_{r1}$ in the bad state of the world with known probability $(1 - p)$. If there is ambiguity, then x_r is an ambiguous crop, because p is not known with certainty.

It is important to consider the ambiguous, rather than risky case, because when farmers are choosing their portfolios, they often do so with little knowledge of possible crops' the yield distributions. Because new crops and new crop varieties are frequently entering the market (the Green Revolution' High Yielding Varieties or the Gene Revolution's transgenics), these crops could be seen more as ambiguous than risky. The following subsections consider the portfolio choice under ambiguity neutrality and aversion, and seek to qualify the effect of risk aversion and ambiguity aversion on diversification.

2.1 Portfolio Choice for the Ambiguity Neutral Farmer

We begin by solving the problem for the ambiguity neutral agent (where $\tau = 0$). Combining (2) and (3), the farmer's problem is thus:

$$\max_{\alpha} EV(x) = \int_{\underline{p}}^{\overline{p}} \left[p\frac{(\alpha x_{r1} + (1-\alpha)x_s)^{(1-\rho)}}{1-\rho} + (1-p)\frac{(\alpha x_{r2} + (1-\alpha)x_s)^{(1-\rho)}}{1-\rho} \right] dp \tag{5}$$

$$\text{subject to:} \qquad 0 \leq \alpha \leq 1 \qquad \text{and} \qquad 0 \leq \underline{p} < \overline{p} \leq 1 \tag{6}$$

Solving the integral in (5), and letting $\widehat{p} = \frac{1}{2}(\overline{p} + \underline{p})$ be the mean probability of the good state, then the farmer solves the following subject to the constraints in (6):

$$\max_{\alpha} EV(x) = (\overline{p} - \underline{p}) \left[\widehat{p}\frac{(\alpha x_{r1} + (1-\alpha)x_s)^{(1-\rho)}}{1-\rho} + (1-\widehat{p})\frac{(\alpha x_{r2} + (1-\alpha)x_s)^{(1-\rho)}}{1-\rho} \right] \tag{7}$$

The Kuhn-Tucker condition is $\frac{\partial EV(x)}{\partial \alpha}\alpha = 0$. If $\frac{\partial EV(x)}{\partial \alpha} < 0$, then $\alpha = 0$, and the farmer opts to invest all of her wealth in the safe crop. The more general case is the interior solution where $\frac{\partial EV(x)}{\partial \alpha} = 0$ and $\alpha > 0$:

$$\frac{\partial EV(x)}{\partial \alpha} = (\overline{p} - \underline{p}) \left[\widehat{p}\frac{(x_{r1} - x_s)}{(\alpha x_{r1} + (1-\alpha)x_s)^{\rho}} + (1-\widehat{p})\frac{(x_{r2} - x_s)}{(\alpha x_{r2} + (1-\alpha)x_s)^{\rho}} \right] = 0 \tag{8}$$

The optimal share of wealth dedicated to the risky asset, α^*, is the solution to (8):

$$\alpha^* = \frac{(Z^{1/\rho} - 1)x_s}{(Z^{1/\rho} - 1)x_s + (x_{r1} - Z^{1/\rho}x_{r2})} \tag{9}$$

where

$$Z = \frac{\widehat{p}(x_{r1} - x_s)}{(1-\widehat{p})(x_s - x_{r2})} \tag{10}$$

Note that Z is always positive because of (1) and because $0 \leq \widehat{p} \leq 1$. Whether Z is greater than, equal to, or less than 1 will depend on whether the expected yield of the risky asset is greater than, equal to, or less than the expected yield of the safe crop:

$$\begin{aligned} &Z > 1 \quad \text{if: } E(x_r) = \widehat{p}x_{r1} + (1-\widehat{p})x_s > E(x_s) = x_s \\ &Z = 1 \quad \text{if: } E(x_r) = E(x_s) \\ &Z < 1 \quad \text{if: } E(x_r) < E(x_s) \end{aligned} \tag{11}$$

We are interested in how the share of wealth the farmer chooses to invest in the risky crop responds to her attitudes towards risk. Thus, we are interested in evaluating the derivative (especially its sign) of α^* with respect to the coefficient of relative risk aversion ρ:

$$\frac{\partial \alpha^*}{\partial \rho} = -\frac{1}{\rho^2} \cdot \log Z \cdot Z^{1/\rho} \cdot \frac{(\alpha x_{r2} + (1-\alpha)x_s)}{(Z^{1/\rho}-1)x_s + (x_{r1} - Z^{1/\rho}x_{r2})} \tag{12}$$

Since $\rho^2 > 0$ and $\alpha x_{r2} + (1-\alpha)x_s > 0$ (because $0 < \alpha \leq 1$), then:

$$\text{Sign}\left(\frac{\partial \alpha^*}{\partial \rho}\right) = \text{Sign}\left(-\log Z \cdot Z^{1/\rho} \cdot \frac{1}{(Z^{1/\rho}-1)x_s + (x_{r1} - Z^{1/\rho}x_{r2})}\right) \tag{13}$$

Because the share of the farmer's wealth invested in the risky crop (α^*) is dependent on the relative expected yields of the safe and the risky crop (Z), understanding whether more risk averse agents diversify more or less (i.e. invest more or less in the risky crop) requires investigating the three different cases in (11). This is a potentially important distinction because different priors on the probability of having a good outcome may lead to different cases and thus possibly to different implications for the derivative in (12).

2.1.1 Comparative Statics when $E(x_r) > E(x_s)$

If the expected yield of the risky crop is greater than the yield of the safe crop then by (11), $Z > 1$. In this case, $\log Z > 0$ and $\text{Sign}\left(\frac{\partial \alpha^*}{\partial \rho}\right) = \text{Sign}\left(-Z^{1/\rho} \cdot \frac{1}{(Z^{1/\rho}-1)x_s + (x_{r1} - Z^{1/\rho}x_{r2})}\right)$, which depends on whether ρ is positive (risk averse) or negative (risk loving).

For a risk averse farmer ($\rho > 0$), $Z^{1/\rho} > 1$ where $\lim_{\rho \to \infty}(Z^{1/\rho}) = 1$. Thus, since $\alpha > 0$, both the numerator and the denominator of (9) are positive. Since the denominator of the last term in (13) is the same as the denominator of (9), then $\frac{\partial \alpha^*}{\partial \rho} < 0$. The risk averse farmer reduces the share of her wealth invested in the risky crop as her risk aversion increases.

For a risk loving farmer ($\rho < 0$), $Z^{1/\rho} < 1$ where $\lim_{\rho \to -\infty}(Z^{1/\rho}) = 1$. Thus, since $\alpha > 0$, both the numerator and the denominator of (9) are negative. Since the denominator of the last term in (13) is the same as the denominator of (9), then $\frac{\partial \alpha^*}{\partial \rho} > 0$. The risk loving farmer increases the share of her wealth invested in the risky crop as her risk aversion increases.

2.1.2 Comparative Statics when $E(x_r) = E(x_s)$

In this case, $Z = 1$, $\alpha^* = 0$ and thus $\frac{\partial \alpha^*}{\partial \rho} = 0$. The farmer does not diversify and only plants the safe crop. No degree of risk aversion causes the farmer to diversify away from the safe crop.

2.1.3 Comparative Statics when $E(x_r) < E(x_s)$

If the expected yield of the risky crop is less than the yield of the safe crop then by (11), $Z < 1$. In this case, $\log Z < 0$ and $\text{Sign}\left(\frac{\partial \alpha^*}{\partial \rho}\right) = \text{Sign}\left(Z^{1/\rho} \cdot \frac{1}{(Z^{1/\rho}-1)x_s + (x_{r1} - Z^{1/\rho}x_{r2})}\right)$, which depends on whether ρ is positive (risk averse) or negative (risk loving). This case is the same as when $E(x_r) > E(x_s)$: a risk averse farmer decreases the share of her wealth in the risky crop, while the risk loving farmer increases this share.

2.1.4 Comparative Statics for the Risk Neutral Farmer

Since $Z^{1/\rho}$ is undefined for the risk neutral ($\rho = 0$) farmer, the derivative (12) is undefined.

2.1.5 Summary for the Ambiguity Neutral Farmer

We have derived the portfolio choice problem for the ambiguity neutral ($\tau = 0$) farmer. Regardless of the farmer's priors about the probability that the good state will realize (and regardless of her priors about the difference between the expected yields of the risky and safe crops), an increase in risk aversion decreases the share of her wealth invested in the risky crop if she is risk averse, but increases it if she is risk loving.

While we present both the case of the risk averse and the risk loving farmer, the literature generally considers farmers as risk (see Dercon (1996) and the literature cited in Engle-Warnick et al. (Forthcoming)). Thus, in when we turn to the data, we expect that the share of the risky crop in a farmer's portfolio decreases in risk aversion. In other words, we expect risk aversion to decrease the extent of diversification. In addition, note that very risk averse agents do not diversify at all: from (9) we see that $\lim_{\rho \to \infty}(\alpha^*) = 0$.

That said, the proportion of her wealth invested in the risky crop depends on the relative priors on the probability of the good state occurring, because α^* depends on Z, which in turn depends on $\widehat{p}$, i.e. the average of the farmer's prior about the most likely and least likely probability of the good state occurring. However, it is impossible to say whether a decrease in the ambiguity $(\overline{p} - \underline{p})$ leads to an increase (or decrease) in α^*.

Because the ambiguity neutral case corresponds closely to the case investigated by Dercon (1996), it is important to mention how our results change in the presence of savings and borrowing constraints. Adopting the same framework as Dercon (1996), where farmers are able to accumulate assets (A^*) or borrow, one can show that the share of the farmer's wealth invested in the risky crop in the presence of savings or borrowing constraints (α') is:

$$\alpha' = \frac{(Z^{1/\rho} - 1)(x_s + A^*)}{(Z^{1/\rho} - 1)x_s + (x_{r1} - Z^{1/\rho}x_{r2})} \tag{14}$$

It is also straightforward to see that Sign $\left(\frac{\partial \alpha^*}{\partial \rho}\right)$ = Sign $\left(\frac{\partial \alpha'}{\partial \rho}\right)$. In other words, risk averse farmers' credit constraints do not affect whether the proportion of the wealth (or land) invested in the risky crop decreases in risk aversion. While a farmer who holds non-crop assets wants to increase the proportion of wealth or land dedicated to the risky crop relative to a farmer with no non-crop assets, the sign of $\frac{\partial \alpha'}{\partial \rho}$ is always negative as long as she is risk averse.

2.2 Portfolio Choice for the Ambiguity Averse Farmer

We now turn our attention to the portfolio choice problem of the ambiguity averse farmer. This corresponds to the case where $\tau > 0$. The farmer must thus chose α to maximize her expected utility as follows:

$$\max_{\alpha} EV(x) = \int_{\underline{p}}^{\overline{p}} \frac{1 - e^{-\tau\{p\frac{1}{1-\rho}(\alpha x_{r1}+(1-\alpha)x_s)^{(1-\rho)}+(1-p)\frac{1}{1-\rho}(\alpha x_{r2}+(1-\alpha)x_s)^{(1-\rho)}\}}}{1 - e^{-\tau}} dp \tag{15}$$

$$\begin{aligned} \text{subject to:} \qquad 0 \leq \alpha \leq 1 \qquad \text{and} \\ 0 \leq \underline{p} < \overline{p} \leq 1 \end{aligned} \tag{16}$$

Unfortunately, no closed form solution for α exists here. However, Klibanoff et al. (2007) provide numerical simulations. They provide two portfolio choice examples. The first example is the allocation of wealth between a safe and an ambiguous asset. In this case, they find that ambiguity aversion and risk aversion work in the same direction. Specifically, holding constant relative risk aversion, an increase in ambiguity aversion decreases the share of wealth dedicated to the ambiguous asset. Furthermore, their analysis shows that imposing ambiguity neutrality overstates the importance of risk aversion.

The second portfolio choice example they present is where agents allocate their wealth among safe, risky and ambiguous assets. In this case, they find that risk aversion and ambiguity aversion can work in opposite directions. Holding fixed the agent's ambiguity aversion, an increase in relative risk aversion increases his holdings of the ambiguous relative to the risky asset. This is because the agent finds it optimal to diversify away from the safe asset and, as long as the risky and ambiguous assets are imperfectly correlated, a more diversified portfolio is preferred to a less diversified one. Meanwhile, holding fixed relative risk aversion, the agent decreases his holdings of the ambiguous relative to risky asset. This is because the ambiguous asset becomes "a less effective diversifier and less valuable." In both cases, an increase in risk aversion leads to an increase in the share of wealth allocated to the safe asset.

What does this imply for our farmer? In the case of a risk averse farmer choosing among different crops, risk aversion clearly causes her to invest more in the safe crop and thus diversify less. However, if the farmer is faced with alternatives of differing levels of uncertainty about the expected yield, then the level of diversification is lower than the implied risk aversion when we ignore ambiguity aversion. Put another way, for a given level of relative risk aversion, an increase in ambiguity aversion, reduces the share of wealth or land allocated to the ambiguous crop. Thus, an increase in ambiguity aversion for a given level of risk aversion reduces diversification away from the safe asset.

2.3 Testable implications

The bottom line is that the more risk averse the farmer is, the less she diversifies away from the safe crop. However, in environments where she has little information about the probability that the high outcome occurs, her portfolio diversification also decreases in ambiguity aversion. If she chooses among only risky crops (or varieties), then we should only find that risk aversion is a significant predictor of her portfolio choice. However, if she chooses among ambiguous crops (or varieties), then, holding fixed her risk aversion, we expect that ambiguity aversion also reduces her portfolio diversification. Furthermore, the effects of uncertainty should be stronger where *ex-post* risk management strategies are unavailable. Thus, we would expect the effects of risk and ambiguity aversion to be stronger among farmers who have less access to formal credit or insurance.

The empirical analysis below considers both crop and varietal diversification. The model predicts that both risk and ambiguity aversion will cause less diversification away from the safe crop or the safe variety. We expect ambiguity aversion to be particularly strong in the case of varietal diversification. Thanks to the Green Revolution's High Yielding Varieties or the transgenics developed in the Gene Revolution, farmers are often presented with new varieties with which they have little or no experience. They are often reluctant to adopt these varieties because not only do they not know whether they will get a high or a low yield at harvest (which is also true for the varieties they know well and already plant), but they might not even know the probability with which the high or low yield will occur.

3 Experimental Design

Our experimental design tests the hypotheses of the previous section by providing a set of explanatory variables that we combine with information from our socioeconomic survey.[2] First, this section describes how we measure farmers' risk and ambiguity aversion, as well as a measure that we use to diagnose whether our subjects understand the experiment. Second, we explain how we map the experimental measures to variables that we will use in our empirical analysis. Finally, we outline our experimental procedures where we describe our subject pool and sessions.

3.1 Risk Aversion Measure

Figure 1 shows the instrument, inspired by Eckel and Grossman (2003) and denoted 'five options' (FO), which we use to derive our preference measure. Our subjects are instructed to select exactly one of the five options. Each option is represented by a circle which contains two payoffs, each with a 50% probability of occurring. To illustrate, the top option pays 26 Nuevos Soles (S/.) with certainty, while the option to its right has a low payoff of 2 S/. with 50% probability and a high payoff of 62 S/. with 50% probability.[3] The variance in the payoffs increases as we move counter clockwise from the top option.

Our measure of risk aversion (RA) is derived by decomposing FO into a set of four binary choices. This decomposition resembles the instrument in Holt and Laury (2000).

[2] This design is identical to the one used in Engle-Warnick and Laszlo (2006), where we run the sessions in a traditional laboratory environment.

[3] 10 S/. were approximately equal to $3 US in 2006.

Figure 2 presents this decomposition. Each row in the figure corresponds to a single binary choice between two alternative gambles. Specifically, each row depicts a choice between two alternatives that are contiguous in the FO instrument. Beginning with the first row of choices and moving down, an expected utility maximizer will at some point switch from the left-hand side gamble with lower variance to the right-hand side gamble with a higher variance and slightly higher expected utility. The sooner the subject switches from the left-hand side to the right-hand side, the less relatively risk averse she is.[4]

3.2 Ambiguity Aversion Measure

Our instrument to measure ambiguity aversion (AA) is depicted in Figure 3, which presents five decisions, one in each row. In the figure, the gamble on the left displays the possible prizes, but not the probability of winning those prizes (this is communicated by eliminating the vertical line in the center of the circle). The gamble on the right contains the same prizes, but with a 50/50 chance of winning each one. However, if a subject chooses the gamble on the right, she must pay 0.50 S/. of her final earnings back to the experimenter for making this choice.[5] Thus the left gamble is ambiguous in the sense that the subject does not know the probability distribution over outcomes, and the costly right gamble provides the subject with an opportunity to reveal her preference to avoid this ambiguity.[6]

Our measure of ambiguity aversion reflects choices for simplification that we had to make to run our laboratory experiment in Peru. There are at least two other methods we could have used. Perhaps the most standard way to measure ambiguity aversion in the laboratory

[4] Our motivation for decomposing FO into RA was to use the relatively simple 50/50 choice gambles within a framework within which we could study the effect of adding additional alternatives to the choice set. The experimental design also consists of a set of questions that study the effect of additional choices. For a description of this aspect of the design, see Engle-Warnick et al. (forthcoming).

[5] In no case can this ever result in a negative payoff for choices in the experiment.

[6] In this case, as in the Ellsberg Paradox, if the distribution over possible distributions of outcomes in the ambiguous gamble is uniform, an expected utility maximizer should be indifferent between the two gambles, and should not pay to avoid the ambiguous gamble. Ellsberg (1961) suggested the original experiments which form the basis of the literature on ambiguity preferences.

is to elicit subjects' willingness to pay for the ambiguous gamble and for the unambiguous gamble separately, then take the difference between the two valuations as the measure. This requires using the Becker, Degroot, Marschak (1964) procedure, in which subjects report their valuation of the gamble, then they sell the gamble to the experimenter if a random number comes up larger than their valuation, and play the gamble if it comes up smaller.

We could also have varied the amount of money it cost to select the unambiguous gamble across the five gambles we used for the measure, taking the minimum amount subjects were willing to pay as our measure. This would have involved either choosing one of the gambles and varying the price each time it was presented, or determining how to vary the price among the five different gambles presented.

We chose our simpler design with multiple gambles and a single price to measure ambiguity aversion because it avoids the complicated Becker, DeGroot, and Marschak (1964) procedure of elicitation, because it is easy to derive a measure from, and because it enabled our ambiguity test to mirror our risk preference tests as closely as possible.

3.3 Diagnostic Measure

In Engle-Warnick et al. (forthcoming), we document an important preference for payoff-dominated alternatives among a different sample of peruvian farmers. Specifically, we find that those subjects chose payoff-dominated alternatives 25% of the time they were available among a set of three alternatives.[7] Since the choice of a dominated alternative calls into question subjects' understanding of the experiment, or subjects' motivation for participating in the experiment, we obtain a measure of this preference and use it as a diagnostic tool to check the robustness of our results.[8]

[7] Hamoudi (2006) also reports "gamble averse" subjects, who prefer a sure amount of money over a gamble, where the lower of the two amounts that can be won in the gamble is equal to the sure amount.

[8] We thank Debraj Ray for a private discussion emphasizing that failure to get the first-order problem right (i.e., payoff dominance), can call into question the usefulness of testing for the second order problem (i.e., risk preference). We believe that there are reasons that subjects may legitimately prefer a payoff-

Figure 4 shows the five choices subjects faced with a payoff-dominated gamble.[9] For each of the five base gambles, we simply test whether subjects would prefer a gamble that is dominated in both possible payoffs. This measure can be thought of as a measure of the subjects' ability to understand the decision-making problem, or a measure of a type of subject who for some reason legitimately prefers to leave money on the table.

3.4 Explanatory Variables Generated by the Experiment

We construct an explanatory variable for each one of the two behavioral measures in our experiment. First, to measure risk aversion, we take the four decisions depicted in Figure 2, noting that each decision is a choice between a relatively safe and a relatively risky gamble. For the risk aversion measure we simply count the number of safe choices made by a subject. The more safe choices, which can take on integer values from zero to four, the more risk averse a subject is. This measure is equivalent to the one used by Holt and Laury (2002).

Second, to measure ambiguity aversion, precisely as in our measure of risk aversion, we count the number of times a subject pays to avoid an ambiguous gamble in each of the five choice problems shown in Figure 3. This measure takes on integer values from zero to five. For a simple model of decision-making, one can think of a subject who has a predisposition against ambiguity. The higher this predisposition, the more likely the subject is to pay to avoid it.

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dominated choice. See Engle-Warnick, et al. (forthcoming) for a discussion of the decision rule that leads to selection of dominated alternatives.

[9] These five decisions were presented to the subjects randomly within the session booklet.

3.5 Experimental Procedures

3.5.1 Subject Pool

In February of 2006, we held two sessions in the district of Cañete (on the Coast) and five sessions in the Mantaro river valley (in the Central Sierra). All seven communities are rural communities, where agriculture is the main livelihood. Though these communities do not specialize in a particular crop, maize and potato are the dominant crops. These crops are typical Peruvian crops and are both consumed locally and sold in larger domestic markets.

In Cañete, we held one session with 19 subjects in Unanue, a community with 283 dwellings, and the other with 25 subjects in La Pampilla, a community with 134 dwellings. In the Mantaro river valley, we alternated sessions on either side and each community was located in a different district.[10] In the district of Paccha, we ran a session with 25 subjects from the community of Buenos Aires (which has 52 dwellings). In the district of Acolla, we ran another session with 25 subjects in Tambopaccha, a community with 90 dwellings. In the district of Matahuasi, we had 25 subjects from Yanamuclo (213 dwellings). In the district of Orcotuna, we had 15 subjects from the community San Antonio (52 dwellings). Finally, in the district of Sicaya, we had 25 subjects in Anexo La Libertad, a community with 101 dwellings.[11]

We visited each of the seven communities several days in advance to recruit subjects with the help of community leaders, who also helped arrange the locales (schoolrooms or community halls) in which to run the sessions. Subjects were recruited based on the following criteria: they had to be of legal age (18 and above), be farmers, reside in the community where the session was to be held, and had to have basic literacy and numeracy skills.

Since the community leaders played an important role in recruiting subjects for the

[10] We did this to minimize potential contamination from one session to the other in this densely populated region. Because kinship ties are strong in contiguous communities and weak across the river and non-contiguous communities, it is unlikely that word would travel quicker than the experimenters and surveyors from one field site to the other.

[11] The population data are from the 2005 Peruvian census, available on-line at `www.inei.gob.pe`.

session, it is unlikely that we have a random sample.[12] However, given the small sizes of the communities that we visited, our subjects are representative of their communities. For instance, since subjects did not come from the same households, a session with 25 subjects would represent 25 different households. Thus, in a community with 52 dwellings (such as Buenos Aires), our session involved subjects from almost 50% of households. At the very least, in the case of Yanamuclo, we sampled from just over 10% of households.

3.5.2 Experimental Sessions

We ran our sessions as laboratory experiments in the field.[13] Subjects were given a show-up fee of 10 S/. upon arrival to cover their transportation and opportunity cost, which is roughly what an agricultural laborer earns in a day. We pay the show-up fee immediately to build trust in the incentivized part of the experiment. Two of our surveyors, each native Spanish speakers, read the instructions from a script.[14] The subjects were given a booklet containing forty-four pages, each page containing one decision.[15] For each decision, subjects indicated their choice by pen. After subjects completed their booklets we verified that each page had exactly one choice marked on it. To control for the effects of order in presenting the choices, the order of the decisions as well as the left/right presentation of the gambles was randomly determined for each subject.

The gambles were implemented by drawing chips out of a bag. For this we used three separate bags, one for each type of randomization required by the experiment. The first bag contained forty-four numbered chips and determined which page of the booklet would be selected for payment. The second bag contained five blue and five yellow chips and determined the outcome of a 50/50 gamble with known probabilities. The third bag contained a

[12] It was necessary to involve the community leaders so as to ensure the community's cooperation.

[13] Harrison and List (2004) call this an artefactual field experiment.

[14] An English version of the instructions are provided in Appendix 1 (the Spanish version is available upon request).

[15] These decisions consisted of the fourteen decisions in RA, AA, and DC plus the questions with additional alternatives in the choice set, which we do not analyze here.

number of blue and yellow chips which we determined randomly by drawing from a uniform distribution from all possible combinations of yellow and blue chips just before the session. When subjects played the gambles, they were first asked which color they chose, blue or yellow, to represent the higher of the two possible payoffs.[16] They then pulled a chip from the appropriate bag to determine their earnings. Subjects were permitted to see the composition of the chips in the ambiguous bag if they desired after the draw. No subject ever asked to do so. Subjects also pulled the chip that determined the choice that was played for pay.

The experiments were held in either a schoolroom or a public meeting room. Only the subjects and experimenters were in the room at the time of the experiments, and outside distractions were carefully minimized. Subjects with relatively poor vision or hearing were seated at the front of the room to facilitate understanding of the instructions.

One-hundred and sixty subjects participated in the experiments, with session sizes of approximately twenty.[17] Subjects earned an average of 25 S/. in addition to the 10 S/. show up fee. The experiments lasted approximately one hour, and the entire time spent on the experiments and the survey was approximately 4 hours per session. Subjects first participated in the experiment, then individually completed the survey, and then were paid their earnings from one randomly chosen gamble choice in private.

4 Survey & Construction of Variables of Interest

4.1 Survey

After the experiment, subjects were directed towards the surveyors with whom they orally completed a socio-economic survey lasting 30 to 45 minutes per subject. The survey con-

[16] Charness and Gneezy (2003) used this experimental procedure.

[17] Sample sizes in lab experiments in the field studying risk preferences in developing countries tend to be quite small. Our study compares in sample size with Binswanger (1980) who had 240 farmers and Shahbuddin et al. (1986) who had 202 farmers.

tained several modules designed to shed light on farm decisions, as well as relevant socio-economic controls. The survey contained modules on demographics and education, dwelling construction and materials, economic activity, access to infrastructure and services and agricultural production. The empirical analysis below restricts the sample to 136 subjects, because of missing observations for some variables and because 13 of our subjects planted no crops at all in the last 12 months. The descriptive statistics of our sample and the variables that will be used in the empirical analysis are found in Table 1.

4.2 Diversification

This subsection describes the construction of our dependent variables: crop and varietal diversification. Dercon (1996) uses the proportion of inputs allocated to the risky crop (sweet potato in his case). Others use a Herfindahl/Hirschman type of index (e.g. Pope and Prescott, 1980), a Margalef index (e.g. Di Falco et al., 2007) or a Simpson index (e.g. Reardon and Sakurai, 1997), which are all measures of the extent of diversification. Because of data limitations, we consider only measurements of the incidence (rather than extent) of diversification: whether the farmer diversifies her crops and whether she diversifies varieties of the main crop.

We asked respondents questions about their agricultural experiences over the last year. Specifically, we asked questions pertaining to the top three crops planted in the last 12 months such as the years of experience with each crop and whether they at any time received technical assistance. For the main crop, we then asked questions about the top three varieties they planted in the last 12 months, the name of each variety, the years of experience with the particular variety and whether they've received any technical assistance.[18]

[18] We also have some information on the land dedicated to each of the top three crops and top three varieties, so a Herfindahl/Hirschman index would be feasible in theory. However, responses to these questions are unreliable as in many cases these summed to more than total land holdings and in other cases the value was missing. In the first case, it is impossible to disentangle whether they sum to more than total land holdings because of mixed farming or because of reporting error. Either way, and due to the high incidence

We create two binary measures of diversification: whether the farmer produces more than one crop (diversifies across crops) and whether the farmer plants more than one variety of the main crop (diversifies across varieties). In our sample, 67.6% of farmers plant more than 1 crop, while only 43.9% plant more than 1 variety of the main crop (see Table 1).

To gain an appreciation for the types of crops planted by the farmers in our sample, Table 2 breaks down crop types for each of the top three crops. Most farmers (80%) plant potato and maize as their main crop, which are relatively safe. First, because potato and maize are endemic to the Andean region, farmers have generations' worth of experience and knowledge about these crops. For instance, potatoes have been cultivated in the Andes for about 8,000 years, tend to be resistant to cold weather and to a number of diseases and pests (National Research Council, 1989; Horton, 1983 and Carney, 1980). This resistance tends to be stronger among the traditional potato varieties. About 90% of our sampled potato farmers report using traditional varieties. Furthermore, the Mantaro river valley is particularly ideal for growing both potato and maize because of its low risk of frost (Hastorf, 2001) and the lower-lying regions in the valley provide adequate climate for maize (Antezana et al., 2005).[19] These factors contribute to potatoes and maize displaying relatively low yield fluctuations and thus relatively low yield risk. Indeed, annual data at the regional level shows that the coefficient of variation of potato and maize over the period spanning 1950 to 2004 is lower than less endemic crops such as wheat and beans.

Second, because of a high demand for both potatoes and maize, especially locally, there is little risk that farmers will not find a market to sell their product, and because most of these crops are sold on local markets (Horton, 1983), they are less subject to larger world price fluctuations. Since both yield and price or demand risk seem relatively low, we can safely assume that potato and maize are relatively safe crops in our samples.

Table 3 provides a cross-tabulation of frequencies for the number of crops and the number

of missing values, we chose not to use this data and focus instead on the incidence of diversification.

[19] Potatoes (especially the endemic varieties) are particularly robust to higher elevations.

of varieties for the main crop. Recall that the survey only inquired about the top three crops and the top three varieties. Interestingly, those that do not diversify crops tend to not diversify across varieties either. Those that do diversify by having at least three crops also tend to diversify across varieties a lot more.

4.3 Explanatory Variables

Recall that risk aversion is measured by counting the number of times subjects chose the safe gamble. A histogram of this measure is presented in Figure 5. The responses are distributed around a mode of 2. Ambiguity aversion is measured by counting the number of times subjects chose to pay to avoid the ambiguous gamble and is presented in a histogram in Figure 6. The variance in responses for both measures is striking.

Our survey includes a number of questions that allow us to control for a number of demographic, socio-economic and agricultual characteristics. The average participant in the experiment is about 43 years old, most likely the head of the household, married and is almost equally likely to be male or female. Educational attainment is very heterogeneous with just over a quarter of the sample having attained less than completed primary school, over one third having completed primary but attained less than completed secondary, and 14.7% having some post-secondary schooling. Math skills, as measured by the math index, are weak, with the average subject giving less than one correct answer out of three.[20]

While our survey does not include information about income or consumption, we control for wealth in two ways. First, we construct an 'Unmet Basic Needs Index' (UNBI) to approximate a farmer's poverty status.[21] We follow the Peruvian Statistical Agency's formula

[20] Subjects were asked simple algebra questions: $7 \times 3 - 4 =?$; $12 \times 2 - 0.5 =?$; and $31 \div 2 =?$. The math index simply counts the number of correct answers. It is strongly correlated with educational attainment.

[21] An Unmet Basic Needs Index may do more to identify a chronically poor individual than income or consumption because it is less sensitive to transitory income shocks. Furthermore, it is subject to significantly less measurement error because of the simplicity and verifiability of the questions that are asked in the survey. To adequately measure income or consumption in a survey requires a lengthy questionnaire with many questions pertaining to income from various sources over a relatively long period of time (usually from

for the UBNI which takes into account the materials used in the construction of the dwelling walls, floors and roofs, and whether the dwelling has electricity, running water and sanitation. The higher the UBNI, the poorer the farmer. Second, all individuals in the sample hold some land (75% own, the rest rent it). These land holdings are nonetheless small, as the average is at just under 2 hectares (there is one outlier at 15 hectares).

Subjects on average have just over 12 years of experience with the main crop and just over 9 years experience with the main variety of the main crop. Only 30% of the sample has received technical assistance. The average time to reach the nearest agricultural extension services or credit office is about three quarters of an hour. However, underlying these statistics are differences across the Costa and Sierra sub-samples. Because these two regions are geographically and ecologically very different, access to markets and services are very different. Indeed, technical assistance is more frequent among Costa farmers than Sierra farmers, and their access to agricultural extension and credit services are also far better. Because of these regional differences, we will also control for session.

5 Results

5.1 Risk and Ambiguity Aversion Measures

Before analyzing the effects of our behavioral measures on technology choice, we begin by discussing how they correlate with the observable socio-economic characteristics. Specifically, for each behavioral measure (RA and AA), we estimate:

$$Y_i = \mathbf{X_i'}\beta_1 + \mathbf{Z_i'}\beta_2 + \epsilon_i \tag{17}$$

where Y_i is RA or AA, $\mathbf{X_i}$ is a vector of respondent characteristics (e.g. demographics and education), $\mathbf{Z_i}$ is a vector of household, farm and regional controls, and ϵ_i is a stochastic

a month to a year) or detailed consumption expenditures data. To construct an Unmet Basic Needs Index, a simple one page questionnaire typically suffices and is a snapshot of current living conditions.

disturbance term. We estimate the regressions using an ordered probit.

The first column of Table 4 presents the correlates for our measure of risk aversion and the second column presents the results for our measure of risk aversion. The only strongly significant predictor of either measure is household size: farmers from larger households are less ambiguity averse. The relationship between household size and risk aversion is a common finding in the empirical literature on risk aversion. In fact Galor and Michalopoulos (2006) derive an evolutionary model of economic development which highlights the role that risk aversion plays in both fertility and innovation decisions. The result in Table 4 suggests that ambiguity aversion may also be affected by household size.

The UNBI predicts risk aversion: poorer farmers are more risk averse, consistent with the concept of relative risk aversion. The math index is also mildly significant – farmers who scored higher on the math questions are less ambiguity averse. The fact that the math index is significant at all might indicate that some subjects did not fully understand the experiment. This suggests that some robustness analysis will be useful.

5.2 Regression Results

To analyze the effect of RA and AA on diversification, we estimate the following:

$$D_i = \alpha_1 RA_i + \alpha_2 AA_i + \mathbf{X_i'}\gamma_1 + \mathbf{Z_i'}\gamma_2 + \eta_i \tag{18}$$

where D_i is either whether the farmer diversifies across crops or whether the farmer diversifies across varieties for the main crop, $\mathbf{X_i'}$ is a vector of variables including respondent characteristics (e.g. demographics and education), $\mathbf{Z_i'}$ includes household, farm and regional controls and η_i is a stochastic disturbance term.

We expect that risk aversion decreases diversification away from the safe crop. We also expect that ambiguity aversion also decreases diversification and that ignoring ambiguity aversion overstates risk aversion's ability to explain portfolio choice. As the dependent variable reflects the incidence of diversification, our model predicts that risk and ambiguity aversion both reduce the probability of diversification. Table 5 shows the results for crop diversification (columns (1) and (2)) and for variety diversification (columns (3) and (4)). All regressions include session controls. Because of the dichotomous nature of the dependent variables, the results are estimated using the probit model, and the table presents the marginal effects from this estimation, evaluated at the means of the independent variables.

Risk aversion statistically significantly predicts whether a farmer diversifies across crops: the more risk averse the farmer is, the less likely she is to plants more than one crop. Ambiguity aversion, however, does not predict her crop diversification decision. Nonetheless, including our measure of ambiguity aversion in column (2) does decrease the coefficient (in absolute terms) on risk aversion compared to column (1), as predicted by the theory in section 2.[22] The results for variety diversification are quite different: risk aversion is statistically insignificant, but ambiguity aversion strongly negatively predicts diversification across more than one variety of the main crop.[23]

The effect of risk aversion on crop diversification can be explained by the theoretical prediction from the model that risk averse individuals diversify less. Because most main crops planted by our sample of farmers are endemic to the region, have relatively low yield variance and are subject to fewer demand shocks, this supports our model.[24] While risk aversion does not appear to affect varietal diversification, ambiguity aversion does. This result suggests that there is something ambiguous about the outcomes of the main varieties of the main crop: for instance farmers might not have much information about yield or price distributions of some varieties of the main crop.

This makes sense if we think of farmers trying new varieties: they tend not to know as

[22] The effects of risk aversion in columns (1) and (2) are not statistically different from each other.

[23] Note again that the risk aversion estimate is lower in magnitude in column (4) than in column (3), although both are indistinguishable from zero and thus not statistically different from each other.

[24] We will conduct some sensitivity analysis in the following section by restricting the sample to only those farmers whose main crops are endemic.

much about their yield distributions. Indeed, the survey also asked whether any of the top three varieties are new to the farmer. While only 16% responded that one of the top three varieties is new to them, only 9% of those who planted only one variety of the main crop said the variety was new to them. In contrast, of the farmers who planted more than one variety, 26% responded that one of the varieties was new to them.[25]

This point is perhaps best illustrated with anecdotal evidence. At the time of our field work, a local non-profit organization in the Mantaro valley had been trying to convince some of the local communities to plant a potato variety (*Papa Capiro*), which has been successful in many other regions in the Peruvian Sierra. Because of its adaptability to deep-frying, which is not the case of local varieties, the *Capiro* variety is particularly attractive to potato chip distributors such as Frito Lays. However, farmers were reluctant to adopt it until they could observe other farmers' experience with it. In other words, their lack of experience with this variety's performance (despite successful adoption in other regions as well as good performance in field trials), specifically uncertainty about its yield distribution, contributed to slow diffusion in the community.[26]

The evidence provided in Table 5 suggests that both risk aversion and ambiguity aversion affect the farmer's portfolio choice. The fact that these behavioural parameters do indeed predict farm choices implies that markets are not perfect or complete and that farmers are not able to contend *ex post* with risk in this region. Indeed, rural Peru is known to have imperfect credit and insurance market (Vakis (2002) and Guirkinger and Boucher(2006)), and the descriptive statistics suggest that it can take up to three hours to even reach the nearest credit office. We include this measure of access to formal credit in Table 5 (time to reach the nearest credit office) in our regressions, and we find that it is negatively associated with the

[25] Unfortunately, the sample size of those who plant a new variety is too small (only 23 observations) to conduct any meaningful formal analysis.

[26] This anecdote comes from discussions with Ing. Walter León Robles, the Mantaro Office Director of FOVIDA (a well respected local NGO providing technical assistance and agricultural extension services to local producers).

probability that a farmer diversifies. Because this is a weak proxy for access to credit (even if they are close to a credit office, they may not have access to credit because of informational asymmetries and lack of collateral), the estimated coefficient is likely an underestimate of the true effect of credit constraint. Thus, the significance of the behavioural parameters implies weak *ex post* risk management opportunities, confirmed by the poor access to credit.

To see whether the effects of risk and ambiguity aversion are stronger where *ex post* mechanisms are weaker, we re-run these regressions including an interaction term between risk or ambiguity aversion and the time to reach the nearest credit office. While the interaction effects were statistically insignificant, we nevertheless found that the linear effects of risk and ambiguity aversion on diversification are stronger than when not including the interaction term (results not reported but available from the authors).

5.3 Robustness Checks

The results of our analysis so far rest on two assumptions. The first assumption is that the subjects understood the experiment. Second, that our dependent variables measure diversification away from the safe crop or variety. This subsection explores both of these assumptions in more depth.

We conduct robustness checks by using the number of times subjects chose payoff-dominated alternatives (recall Figure 4). The distribution of the number of payoff dominated choices (out of a maximum of five) is displayed in Figure 7. Confirming our findings in Engle-Warnick et al. (forthcoming), Peruvian farmers do indeed reveal a non-negligible preference for payoff dominated alternatives. In an unreported regression paralleling that in Table 4 for the other two behavioural measures, we find that age and performance on the math tests significantly predicted the number of payoff-dominated choices.

If this preference for payoff-dominated alternatives matters for decision-making, we might expect that it also predicts portfolio choice. We begin our robustness analysis by including in regression (18) our measure of payoff-dominated preference. The results can be found in panel A of Table 6. The coefficients on risk and ambiguity aversion remain within one standard deviation of the results in Table 5. The preference for dominated alternatives only statistically significantly predicts portfolio choice at the 10% level in three specifications. The main conclusions from Table 5 remain: risk aversion, not ambiguity aversion, predicts diversification across crops, while ambiguity aversion, not risk aversion, significantly predicts varietal diversification.

Panel B of Table 6 restricts the sample to subjects who chose fewer than four dominated choices.[27] The main results from Table 5 are robust to this sample restriction. Specifically, risk aversion (though more weakly so), not ambiguity aversion, predicts diversification across crops, while ambiguity aversion and not risk aversion predicts diversification across varieties. In fact, the estimated effect of ambiguity aversion on variety diversification becomes even more strongly negative with this sample restriction, indicating that the results we find here might be a lower bound estimate of the effect of ambiguity aversion on portfolio choice.

We pursue the possibility that respondents might not have understood the experiment very well by restricting the sample by age (since we found that the older subjects were more likely to choose dominated alternatives, and are the ones most likely to not understand the experiment due to their low levels of education). In Panel C of Table 6, we exclude subjects aged 60 and above. The results that we found in Table 5 are again robust to this sample restriction, and the magnitudes are greater indicating stronger effects: risk aversion predicts crop diversification and ambiguity aversion predicts variety diversification.

In summary, we have attempted to rule out that the patterns that we found in Table 5 were driven by subjects' inability to understand the experiment. We utilized two proxies of this inability, one of which is a measure generated by our experiment: preferences for dominated alternatives and age. The robustness analysis conducted here does not force us

[27] Restricting the sample to those who never chose the dominated alternative or who chose it only once reduces the sample size so much that the regressions become insignificant.

to overturn our main results.

Finally, our interpretation rests upon the assumption that most of the main crops planted by our subjects are relatively safe because they are endemic to the region. To test this, we restrict the sample of farmers who plant main crops which we know are endemic: potatoes, corn, yuca, quinoa and grass. Doing so reduces the sample by only 14 subjects. The results, presented in Panel D of Table 6, are very similar to our main results in Table 5: risk aversion predicts crop diversification, but ambiguity aversion predicts varietal diversification. Though relatively weaker, the results remain within a standard deviation of the results in Table 5.

6 Discussion

In this paper, we argue that both ambiguity and risk aversion are important in understanding farmers' decision-making under uncertainty. Specifically, in an environment where *ex-post* risk management mechanisms are weak because of imperfect or incomplete credit and insurance markets, farmers must undertake *ex-ante* mechanisms such as crop or varietal diversification which rely on often unknown outcome probability distributions. We adapt a standard model of diversification to the case where the probability of good yield is unknown, and show that ignoring ambiguity aversion can overstate risk aversion's effect on diversification.

What is particularly striking about our results is that ignoring ambiguity aversion would erroneously lead us to conclude that attitudes towards uncertainty does not matter for varietal diversification: ambiguity aversion, not risk aversion, leads to a decrease in the probability that farmers plant more than one variety of the main crop. In addition, we confirm that there are imperfections in *ex-post* risk coping mechanisms as the distance to the nearest credit office is negatively correlated with the probability of diversification away from the safe crop. We show that our main results are not driven by subjects' inability to understand the experimental design. In addition, we show that the main results hold even in the sample which only contains farmers plant endemic crops.

Our model and findings contribute to the literature on decision-making under uncertainty in developing countries by showing that ambiguity aversion, not just risk aversion, is critical in farmers' farm decisions. This is a particularly salient point given that farmers must choose among technologies whose underlying yield distributions are unknown, and this is particularly true of new technologies. In addition, our results provide policy makers with a useful tool to mitigate the negative effects of uncertainty in a poor agricultural society. If risk aversion matters, little can be done other than helping the poor access *ex-post* risk management mechanisms. Such mechanisms are difficult to employ where people are poor, have little collateral and where asymmetric information exists. If ambiguity aversion matters, then policy makers can target their interventions at helping the poor resolve uncertainty about the crops and varieties they use, through agricultural research and extension services.

References

Antezana, I., A. Fabian, S. Freund, E. Gehrke, G. Glimmann, and S. Seher. (2005) "Poverty in Potato Producing Communities in the Central Highlands of Peru." SLE Centre for Advanced Training in Rural Development, Humboldt University of Berlin. Manuscript.

Alderman, H. and C. Paxson. (1992). "Do the Poor Insure? A Synthesis of the Literature on Risk and Consumption in Developing Countries," Agriculture and Rural Development Department, World Bank: Working Paper WPS1008.

Becker, G., M. DeGroot, and J. Marschak (1964). "Measuring Utility by a Single-Response Sequential Method," *Behavioral Science*, 8:4:293-315.

Binswanger, H. (1980). "Attitudes toward Risk: Experimental Measurement in Rural India", *American Journal of Agricultural Economics*, 62:3:395-407.

Carney, H. J. (1980). "Diversity, Distribution and Peasant Selection of Indigenous Potato Varieties in the Mantaro Valley, Peru: a Biocultural Evolutionary Process." International Potato Center, Social Science Department. Working Paper Series No 1980-8.

Charness, G. and U. Gneezy (2003). "Portfolio Choice and Risk Attitudes," SSRN working paper.

Dercon, S. (1996). "Risk, Crop Choice, and Savings: Evidence from Tanzania," *Economic Development and Cultural Change* 44:3:485-513.

Dillon, J. and P. Scandizzo. (1978). "Risk Attitudes of Subsistence Farmers in North Eastern Brazil: A Sampling Approach," *American Journal of Agricultural Economics* 60:425-35.

di Falco, S., J.-P. Chavas and M. Smale (2007). "Farmer Management of Production Risk on Degraded Lands: The Role of Wheat Genetic Diversity in Tigray Region, Ethiopia," *Agricultural Economics* 36:147-156.

Eckel, C. and P. J. Grossman (2003). "Forecasting Risk Attitudes: An Experimental Study of Actual and Forecast Risk Attitudes of Women and Men," Virginia Tech Department of Economics Working Paper.

Ellsberg, D. (1961). "Risk, Ambiguity, and the Savage Axioms," *Quarterly Journal of Economics*, 75:4:643-669.

Engle-Warnick, J. and S. Laszlo (2006). "Learning by doing in an ambiguous environment," Working paper, McGill University.

Engle-Warnick, J., J. Escobal and S. Laszlo (Forthcoming). "How do additional alternatives affect individual choice under uncertainty?" Forthcoming at *Canadian Journal of Economics*.

Feder, G. R. Just and D. Zilberman (1985). "Adoption of Agricultural Innovations in Developing Countries: A Survey," *Economic Development and Cultural Change*, January.

Galor, O. and S. Michalopoulos (2006). "Darwinian Evolution of Entrepreneurial Spirit and the Process of Development," Working Paper, Brown University.

Guirkinger, C. and S. Boucher. (2006). "Credit Constraints and Productivity in Peruvian Agriculture." Economics, Center for Research in Economic Development, University of Namur. Manuscript.

Harrison, G. and J. List (2004). "Field Experiments," *Journal of Economic Literature*, XLII:1013-1059.

Hamoudi, A. (2006). "Risk Preferences in Households and Families", UCLA working paper.

Hastorf, C. (2001). "Agricultural Production and Consumption." in T. N. D'Altroy et al. eds *Empire and domestic economy* New York (NY): Kluwer Academic/Plenum.

Holt, C. and S. Laury (2002). "Risk Aversion and Incentive Effects in Lottery Choices," *American Economic Review*, 96:1644-1655.

Horton, D. (1983). "Potato Farming in the Andes: Some Lessons From on-Farm Research in Peru's Mantaro Valley." *Agricultural Systems* Vol. 12: 171-184.

Instituto Nacional de Estadéstica e Información (INEI) (2008). "Perú: Incidencia de la Pobreza por Área de residencia: 2004-2007", Last accessed June 4th, 2008 `http://www.gob.pe/peruencifrasHTM/inf-soc/pob06.gif`.

Klibanoff, P., M. Marinacci, and S. Mukerji (2005). "A Smooth Model of Decision-Making Under Ambiguity," *Econometrica* 73:6:1849-1892

Morduch, J. (1995). "Income Smoothing and Consumption Smoothing," *Journal of Economics Perspectives*, 9:3:103-114.

National Research Council. (1989) *Lost Crops of the Incas: Little Known Plants of the Andes and their Promise for Worldwide Cultivation.* Washington D.C: National Academy Press.

Pope, R. and R. Prescott. (1980). "Diversification in Relation to Farm Size and Other Socio-Economic Characteristics," *American Journal of Agricultural Economics*, 62:3:554-559.

Reardon, T. and T. Sakurai. (1997). "Potential Demand for Drought Insurance in Burkina Faso and its Determinants," *American Journal of Agricultural Economics*, 79:4:1193-1207.

Shahabuddin, Q., S. Mestleman and D. Feeny (1986). "Peasant Behavior Toward Risk and Socio-Economic And Structural Characteristics of Farm Households in Bangladesh," *Oxford Economic Papers* 38:122-130.

Vakis, R., E. Sadoulet, A. de Janvry, and C. Cafiero. 2002. "Searching for failures in the Peruvian labor market via mixture models." Berkeley University. Manuscript.

Figure 1: 'Five Options' Risk Preference Measurement Instrument

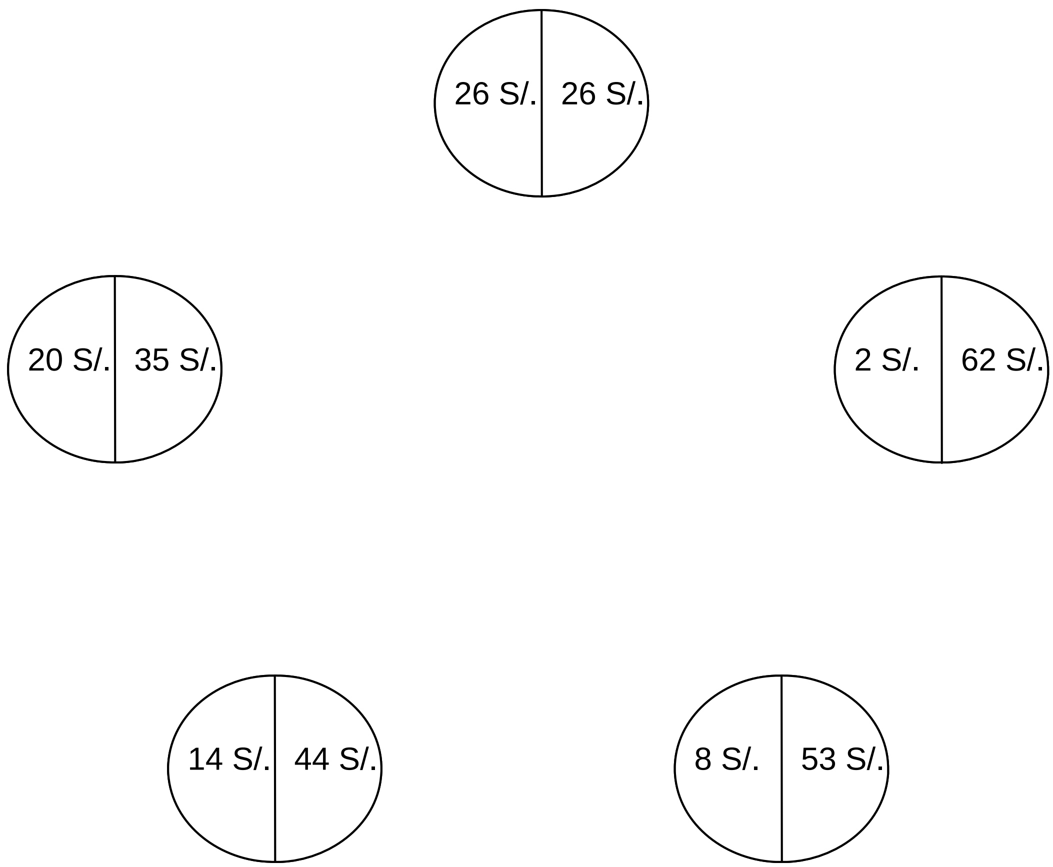


Figure 2: Decomposing the 'Five Options' Instrument into a Series of 'Binary Options' Instruments

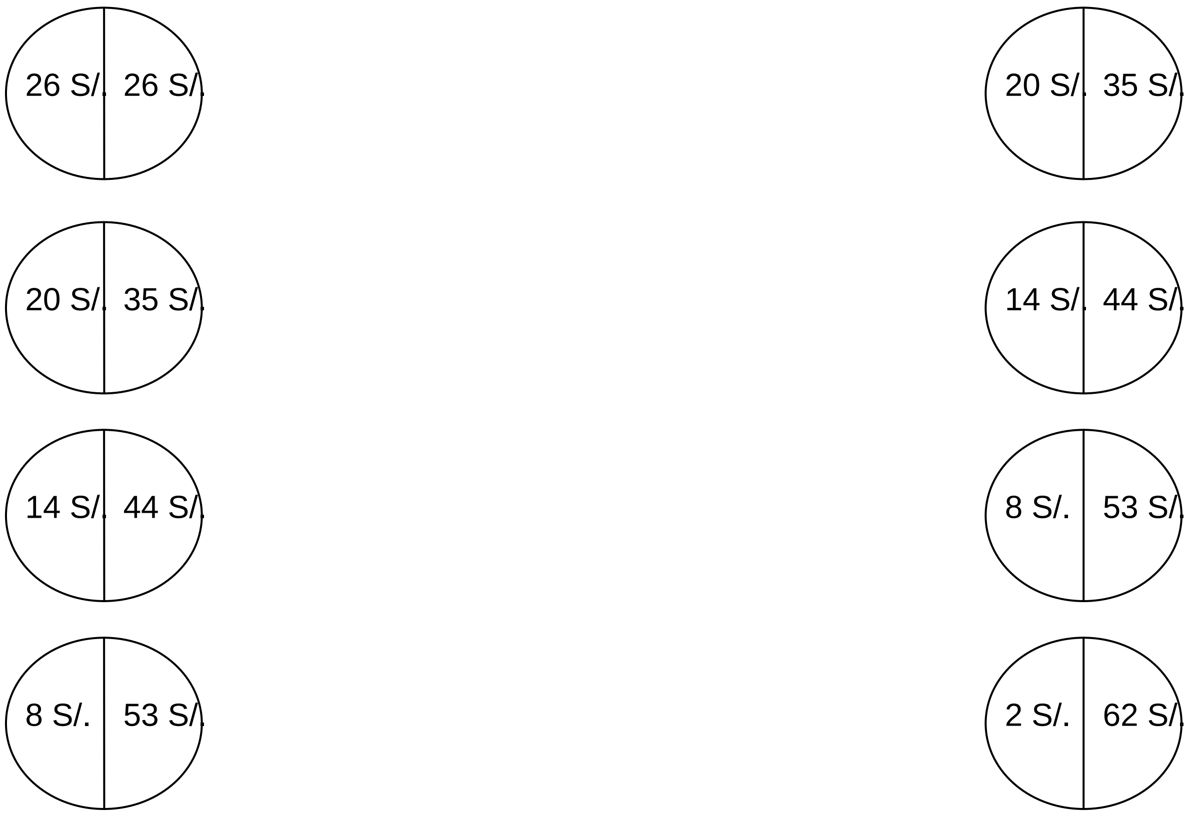


Figure 3: Binary Choices to Reveal Preferences for Ambiguity

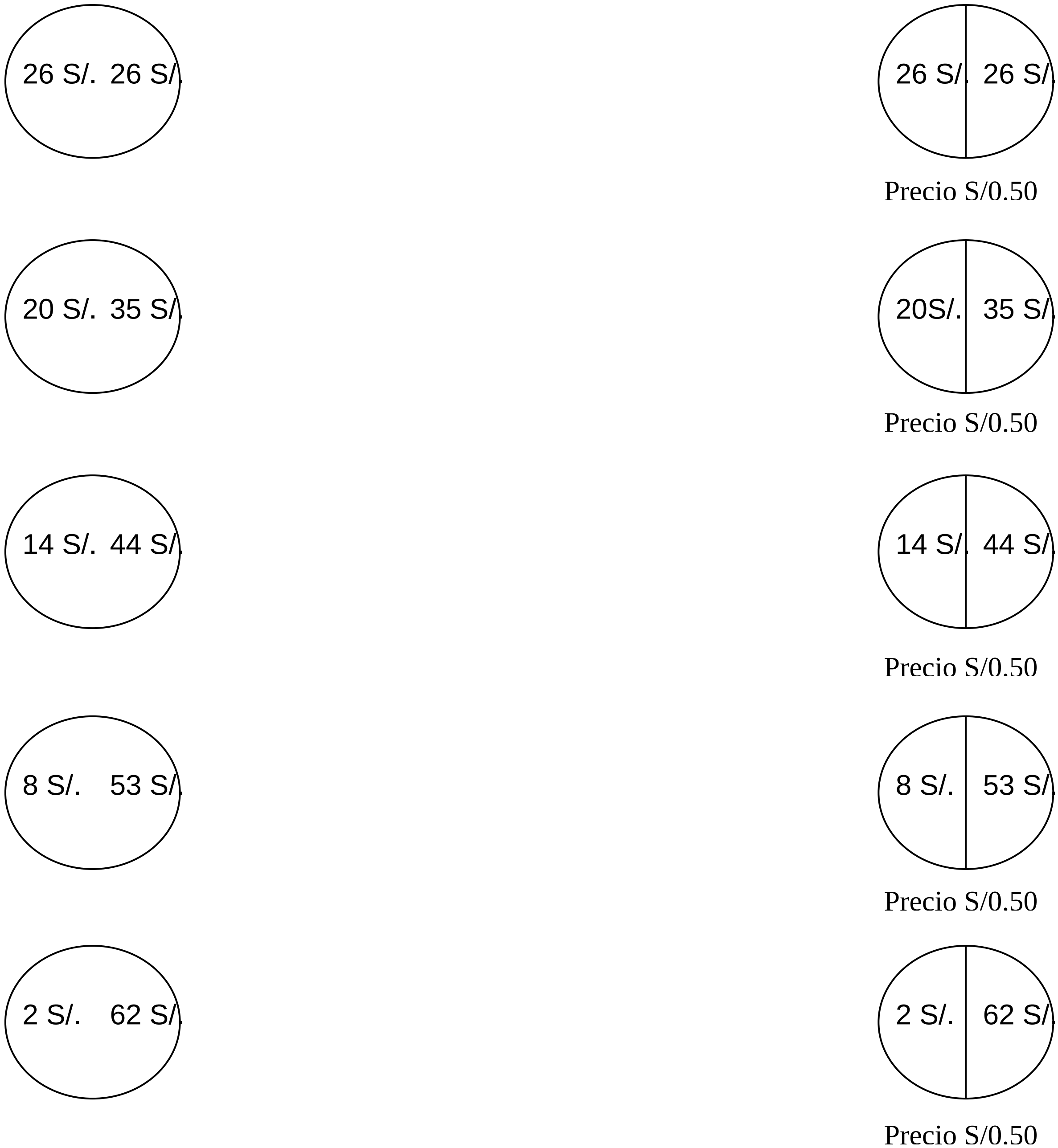


Figure 4: Binary Choices to Reveal Preferences for Dominated Alternatives

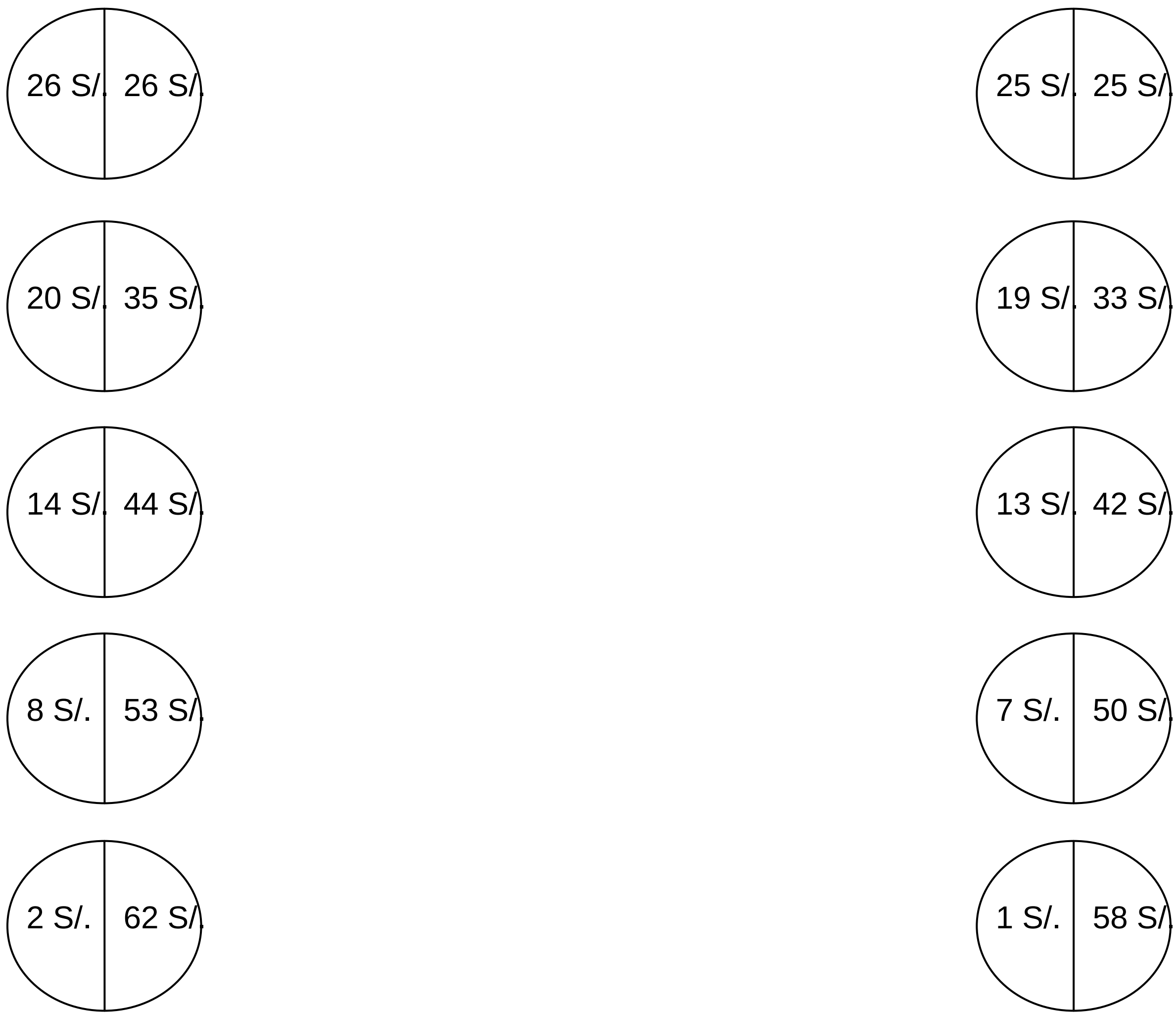
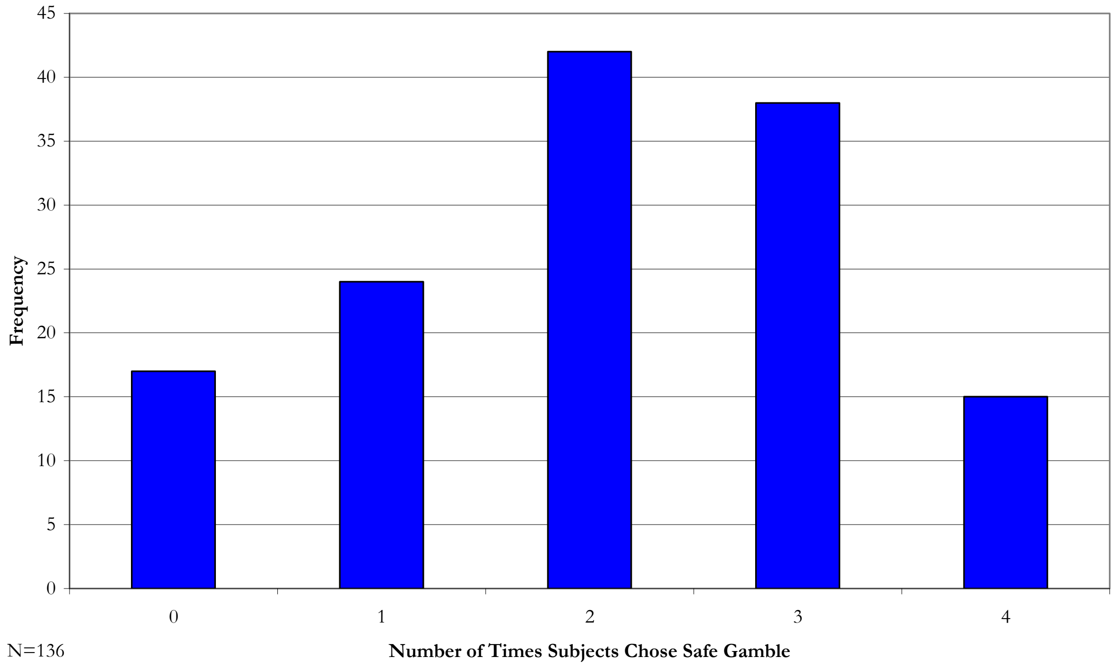
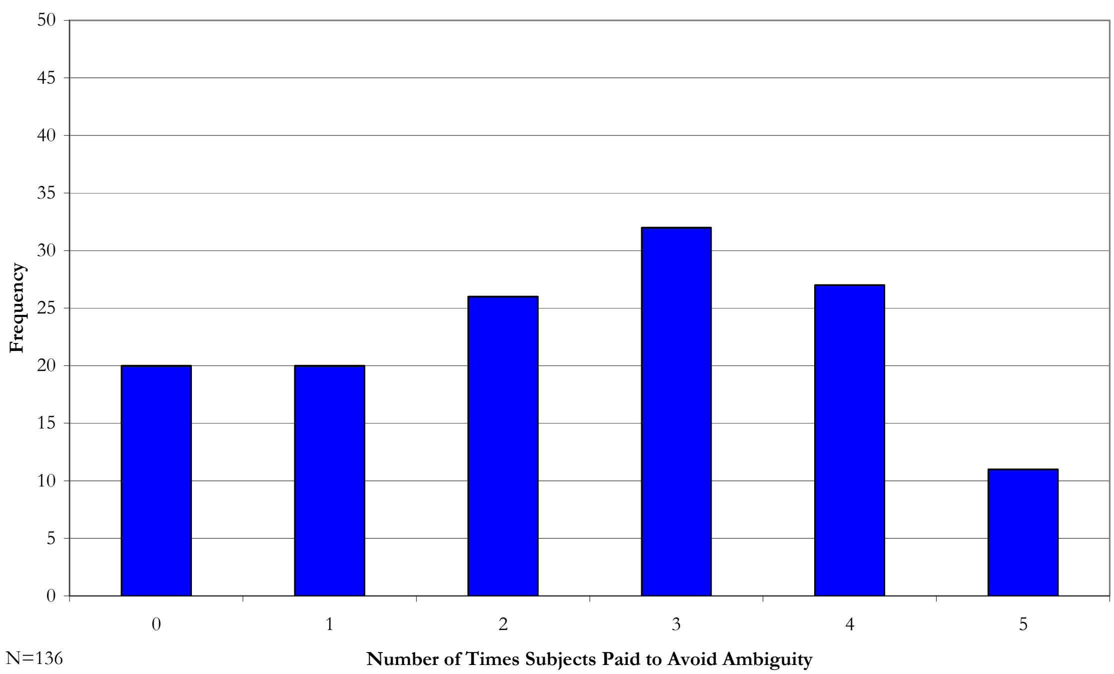


Figure 5 - Risk Aversion



N=136

Figure 6 - Ambiguity Aversion



N=136

Figure 7 - Dominance Preference

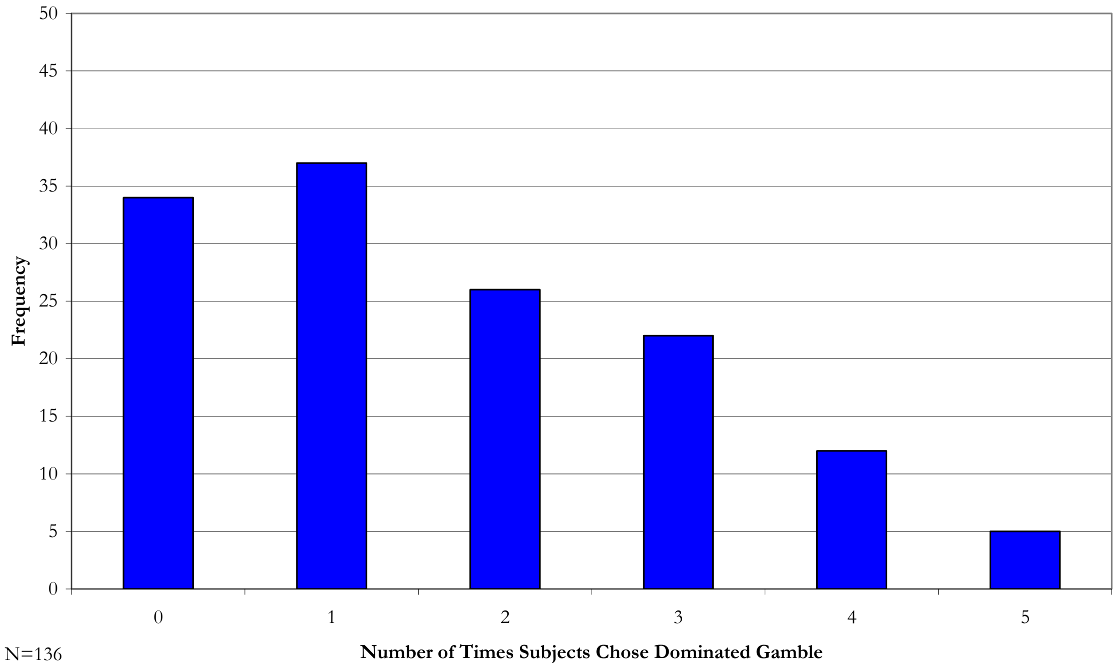


Table 1 - Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
Diversifies crops	0.676	0.470	0	1
Diversifies varieties	0.426	0.496	0	1
Risk aversion	2.074	1.184	0	4
Ambiguity aversion	2.434	1.524	0	5
Age	43.316	14.270	18	78
Household Head	0.757	0.430	0	1
Male	0.559	0.498	0	1
Married	0.735	0.443	0	1
Separated	0.140	0.348	0	1
Single	0.125	0.332	0	1
Less than completed primary	0.272	0.447	0	1
Primary, less than completed secondary	0.375	0.486	0	1
Secondary completed	0.206	0.406	0	1
Post-secondary schooling	0.147	0.355	0	1
Math Index	0.941	1.024	0	3
Household Size	5.412	2.216	1	14
Unmet Basic Needs Index	0.407	0.208	0	0.917
Time to reach nearest agricultural extension services	44.471	31.176	2	180
Time to reach nearest credit office	47.522	30.908	5	180
Main crop is corn	0.316	0.467	0	1
Main crop is potato	0.493	0.502	0	1
Coast	0.257	0.439	0	1
Landsize (Ha)	1.973	1.981	0.025	15
Land is irrigated	0.706	0.457	0	1
Years of experience with the main crop	12.423	11.603	1	60
Received technical assistance with the main crop	0.301	0.461	0	1
Years of experience with the main variety	9.346	9.405	1	50

N=136

Table 2 - Top three crops

Main Crop		2nd Crop		3rd Crop	
Crop name	Frquency	Crop name	Frquency	Crop name	Frquency
potato	67	corn	27	wheat	14
corn	43	barley	20	beans	8
grass	8	beans	16	corn	7
beans	4	potato	13	barley	7
garlic	3	grass	3	potato	6
yuca	2	garlic	2	pea	6
wheat	2	carrot	2	grass	3
quinoa	2	yuca	1	alfalfa	2
grape	2	wheat	1	quinoa	2
carrot	1	quinoa	1	onion	2
barley	1	pea	1	sweet potato	1
alfalfa	1	onion	1	mashua	1
		olluco	1		
		cucumber	1		
		cotton	1		
Total	136	Total	91	Total	59

Table 3 - Cross-tabulation of crop and variety frequencies

	Number of varieties			
Number of crops	1	2	3	Total
1	39 28.68%	3 2.21%	2 1.47%	44 32.35%
2	18 13.24%	11 8.09%	3 2.21%	32 23.53%
3	21 15.44%	20 14.71%	19 13.97%	60 44.12%
Total	78 57.35%	34 25%	24 17.65%	136 100%

Table 4 - Determinants of Risk and Ambiguity Aversion

	Risk aversion	Ambiguity aversion
Age	-0.007	0.007
	(0.011)	(0.010)
Household Head	-0.091	-0.100
	(0.298)	(0.262)
Male	0.333	0.220
	(0.281)	(0.229)
Married	-0.468	0.165
	(0.348)	(0.295)
Separated	-0.189	0.081
	(0.439)	(0.407)
Household Size	-0.084	-0.137
	(0.053)	(0.039)***
Primary, less than secondary completed	0.607	0.017
	(0.444)	(0.465)
Secondary completed	0.513	-0.199
	(0.503)	(0.513)
Some post-secondary	0.903	0.134
	(0.606)	(0.674)
Math index	0.132	-0.276
	(0.121)	(0.130)**
Landsize	0.048	-0.035
	(0.046)	(0.063)
Land is irrigated	-0.158	0.175
	(0.280)	(0.270)
Unmet basic needs index	1.771	-0.344
	(1.023)*	(1.076)
Time to reach nearest agricultural extension services	-0.002	-0.002
	(0.005)	(0.004)
Time to reach nearest credit office	0.002	0.000
	(0.005)	(0.005)
Main crop is corn	-0.001	-0.442
	(0.377)	(0.330)
Main crop is potato	-0.211	-0.263
	(0.357)	(0.373)
Years Experience with the main crop	-0.007	0.011
	(0.013)	(0.012)
Received technical assistance for the main crop	0.167	0.242
	(0.307)	(0.288)
Wald Chi-Squared	54.16***	40.77**
Pseudo R-Squared	0.0908	0.0686
Observations	136	136

Robust standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 5 - Probit Marginal Effects

	Diversify Crops		Diversify Varieties	
	(1)	(2)	(3)	(4)
Risk aversion	-0.053	-0.046	-0.069	-0.053
	(0.028)**	(0.024)**	(0.052)	(0.053)
Ambiguity Aversion		-0.026		-0.090
		(0.020)		(0.037)**
Age	0.000	0.000	-0.009	-0.011
	(0.003)	(0.003)	(0.006)	(0.006)*
Household Head	-0.141	-0.128	0.195	0.164
	(0.046)**	(0.043)**	(0.144)	(0.151)
Male	0.148	0.136	-0.105	-0.050
	(0.077)**	(0.074)**	(0.149)	(0.151)
Household Size	-0.003	-0.007	0.018	-0.004
	(0.013)	(0.013)	(0.026)	(0.026)
Married	0.153	0.125	0.116	0.175
	(0.137)	(0.134)	(0.144)	(0.138)
Separated	0.163	0.144	-0.347	-0.343
	(0.052)***	(0.050)***	(0.141)	(0.139)
Primary, less than completed secondary	0.414	0.360	0.339	0.334
	(0.149)***	(0.149)***	(0.258)	(0.267)
Secondary completed	0.206	0.169	0.507	0.468
	(0.074)**	(0.070)**	(0.224)*	(0.242)*
Post secondary	0.176	0.161	0.395	0.454
	(0.064)**	(0.060)**	(0.310)	(0.297)
Math index	0.028	0.022	0.128	0.083
	(0.039)	(0.038)	(0.079)*	(0.079)
Size of land holdings	0.189	0.171	0.199	0.194
	(0.046)***	(0.045)***	(0.064)***	(0.062)***
Land is irrigated	0.076	0.075	-0.056	-0.083
	(0.100)	-0.093	(0.209)	(0.220)
Unmet Basic Needs Index	1.098	0.917	1.288	1.355
	(0.394)***	(0.358)***	(0.715)*	(0.715)*
Time to nearest agricultural extension services	0.000	0.000	0.002	0.001
	(0.002)	(0.002)	(0.003)	(0.003)
Time to nearest credit office	-0.004	-0.004	-0.004	-0.004
	(0.002)**	(0.002)***	(0.003)	(0.003)
Main crop is corn	0.044	0.041	0.092	0.007
	(0.067)	(0.062)	(0.215)	(0.214)
Main crop is potato	0.105	0.113	0.325	0.275
	(0.078)	(0.077)	(0.176)*	(0.190)
Years experience with the main crop	0.008	0.006	0.011	0.018
	(0.006)	(0.005)	(0.008)	(0.008)**
Received technical assistance with main crop	0.024	0.036	0.302	0.307
	(0.080)	(0.065)	(0.212)	(0.208)
Years experience with the main variety			0.008	0.004
			(0.009)	(0.009)
Wald Chi-Squared	85.38***	90.67***	88.73***	88.52***
Pseudo R-Squared	0.5603	0.5693	0.5071	0.5260
Observations	136	136	136	136

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Huber-White robust standard errors in brackets. All regressions include session controls and control for Coastal communities. Omitted category for marital status: single. Omitted category for education: less than primary. Omitted category for crop type: other.

Table 6 - Robustness Analysis (Probit Marginal Effects)

Dependent Variable	**Diversifies across Crops (Two or Three Crops)**		**Diversifies across Varieties (Two or Three More Varieties of Main Crop)**	
	(1)	(2)	(3)	(4)
Panel A - Including dominated choices in binary dominated gamble				
Risk aversion	-0.056	-0.049	-0.670	-0.053
	(0.026)**	(0.023)**	(0.052)	(0.053)
Ambiguity aversion		-0.022		-0.077
		(0.019)		(0.035)**
Dominated choice	-0.045	-0.039	-0.077	-0.054
	(0.025)*	(0.023)*	(0.046)*	(0.045)
Wald Chi-Squared	80.53***	83.48***	89.14***	96.06***
Pseudo R-Squared	0.5751	0.5819	0.5182	0.5310
Observations	136	136	136	136
Panel B - Excluding subjects who chose more than 3 dominated choices in the binary dominated gamble				
Risk aversion	-0.045	-0.041	-0.061	-0.038
	(0.027)**	(0.025)**	(0.061)	(0.063)
Ambiguity aversion		-0.012		-0.127
		(0.019)		(0.051)**
Wald Chi-Squared	55.94***	59.07***	106.00***	95.85***
Pseudo R-Squared	0.5523	0.5550	0.5659	0.5906
Observations	119	119	119	119
Panel C - Excluding subjects who are above 60 years old				
Risk aversion	-0.081	-0.071	-0.084	-0.086
	(0.042)**	(0.037)**	(0.059)	(0.064)
Ambiguity aversion		-0.040		-0.147
		(0.030)		(0.052)***
Wald Chi-Squared	77.88***	81.71***	114.75***	123.27***
Pseudo R-Squared	0.5214	0.5310	0.5603	0.5909
Observations	119	119	119	119
Panel D - Including only observations if main crop is endemic (potato, corn, yuca, quinoa, grass)				
Risk aversion	-0.036	-0.030	-0.091	-0.070
	(0.025)**	(0.023)**	(0.059)	(0.060)
Ambiguity aversion		-0.012		-0.076
		(0.013)		(0.045)*
Wald Chi-Squared	67.86***	71.79***	89.96***	97.36***
Pseudo R-Squared	0.6231	0.6304	0.5398	0.5896
Observations	122	122	122	122

Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%. All regressions include the same controls as in table 5 as well as session controls.