

# Ambiguity and Insurance

Gharad Bryan<sup>1</sup>

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## Abstract

Why don't people in developing countries insure themselves? I propose that some households are ambiguity averse, and that these households fear any insurance contract they purchase will payout when it is not needed and will not payout when it is. I study two applications of this observation. I first study formal crop insurance, in particular index insurance and the insurance element of limited liability credit. I provide a formal model of ambiguity aversion and derive four implications. First, households that are sufficiently ambiguity averse will not value any actuarially fair insurance contract and will have a lower willingness to pay for any specific contract. Second, because learning diminishes the impact of ambiguity, increased experience with the insured crop will mitigate the effect of ambiguity aversion. Third, increasing risk aversion makes index insurance more valuable for the ambiguity neutral, and relatively less valuable for the ambiguity averse. Fourth, increasing risk aversion has no effect on the demand for limited liability credit (ie, a state contingent transfer) for ambiguity neutral individuals, but increases demand for limited liability credit for the ambiguity averse. I test these predictions using two experiments, one on rainfall insurance in Malawi and one on limited liability credit in Kenya. Both data sets contain baseline measures of ambiguity aversion and risk aversion, and strongly support the theoretical claims. As a second application I study informal risk sharing. I provide a model showing that the same preferences used to study crop insurance can explain the common finding that consumption is sensitive to idiosyncratic income shocks. The model I use assumes that households cannot make accurate probability assessments and entertain a *set* of priors. I assume these households assess uncertain prospects using a prior that minimizes the gain from leaving the endowment. The model implies that households have different beliefs at the optimal contract, creating a wedge between the consumption levels of households giving and receiving transfers in any state. I derive testable implications from the model, which I evaluate using both the ICRISAT village level data from India and the Townsend Thai monthly panel. I am unable to reject the model using either data set.

# 1 Ambiguity Aversion and Missing Insurance Markets

## 1.1 Introduction

Household incomes in the developing world are highly variable and often close to subsistence. If insurance markets were complete, this income variability would not affect consumption and would be of little concern. Insurance markets are, however, far from complete. Formal insurance against variation in crop yield, the bulk of income in many countries, is rarely available, and existing evidence shows that informal insurance mechanisms leave consumption susceptible to idiosyncratic shocks (e.g. [Townsend 1994](#)). This uninsured risk directly reduces welfare for risk averse households, and may have more dramatic effects. At the extreme, missing insurance may lead to death (e.g. witch killing as in [Miguel 2005](#)) and cause poverty traps (e.g. [Dercon and Christiaensen 2010](#)).

This paper studies one possible explanation for missing insurance markets: the production function generating household income is ambiguous and households are ambiguity averse. I show theoretically and empirically that these two factors combine to reduce demand for insurance, leading to missing markets.

Ambiguity aversion is best understood by considering the Ellsberg paradox. [Ellsberg \(1961\)](#) argued that faced with two gambles, one with known odds and one with unknown odds, many people strictly prefer the gamble with known odds, even if they can choose which side of the gamble to take. Subsequent studies have confirmed this intuition and show that a large portion of the population prefers known odds.<sup>1</sup> An agent that behaves in this way is termed ambiguity averse, and the behavior is inconsistent with Subjective Expected Utility theory.<sup>2</sup> The behavior is, however, consistent with a model in which agents entertain a *set* of possible priors and choose using the prior that minimizes their chance of winning. If the set of priors is large when probabilities are unknown, and a singleton when probabilities are known, these agents will prefer known odds. Thus, an ambiguity averse agents “worries” that the odds depend on her choice in such a way that her choices are always wrong.

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<sup>1</sup>See [Camerer \(2003\)](#) for a review of the evidence. The data in this paper suggests that over 50% of the population prefers to bet on known odds.

<sup>2</sup>If the decision maker can take either side of the bet there is no prior that would justify a strict preference for the urn with known odds.

In some circumstances, ambiguity averse individuals will not demand insurance. Consider an individual (Maggie) thinking about purchasing rainfall insurance. Suppose that Maggie's income is jointly dependent on rainfall and locusts. Her income is known to be increasing in rainfall and decreasing in locusts, but the joint distribution of rainfall and locusts is unknown. Maggie believes that after accounting for locusts her income could be increasing or decreasing in rainfall.<sup>3</sup> Maggie's production function could be one of many and she does not know the probability of each of these possibilities – her production function is ambiguous. How should she assess a rainfall insurance contract? If Maggie is ambiguity averse and the insurance pays out when it's dry, she will worry that her income is low when it's wet. On the other hand, if the insurance pays out when it's wet, she will worry that her income is low when it's dry. Maggie may well avoid making the decision, preferring to stay with her endowment – better the devil you know. This choice, however, implies that Maggie is uninsurable – she will not accept any actuarially fair rainfall insurance, no matter its structure.

I formalize this intuition using preferences I call Variational Endowment Anchored (VEA) preferences.<sup>4</sup> When considering an uncertain prospect, VEA households entertain a *set* of priors over the states of the world, and assess expected utility using a prior that minimizes the gain from leaving the endowment or status-quo.<sup>5</sup> These assumptions mean that VEA households display what I call choice dependent caution (CDC). Effective beliefs depend on the prospect under consideration (choice dependence) and are chosen to minimize the gain relative to the status-quo (caution).<sup>6</sup> In the example above, choice dependence means Maggie's effective beliefs depend on whether the insurance is increasing or decreasing in rainfall, and caution leads her to stay with her endowment.

I study the implications of VEA preferences and CDC for two different types of insurance, one formal and one informal. I first study the demand for index insurance and the insurance element of limited liability credit. Index insurance is a formal insurance contract that pays out depending on the realization of an aggregate index. Prominent examples include rainfall insur-

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<sup>3</sup>That is, while the partial effect of rain always increases her income, Maggie does not know whether the correlation between rainfall and locusts will overturn this fact.

<sup>4</sup>These preferences appear in [Dana and Riedel \(2010\)](#) where they are referred to as "Variational Preferences Anchored at  $\omega$ ." In the context of their model  $\omega$  refers to the endowment.

<sup>5</sup>The preferences are closely related to two classic treatments of ambiguity: the Maximin Expected Utility (MEU) preferences of [Gilboa and Schmeidler \(1989\)](#) and the unanimity preferences of [Bewley \(1986\)](#). Agents with VEA preferences have a set of priors as in both these treatments. Similar to MEU agents, VEA agents evaluate prospects using a minimizing prior, but unlike MEU the prior is chosen to minimize the gain from departing from the status-quo. Similar to Bewley preferences, VEA agents do not depart the status-quo or endowment unless they can find an option that is preferred to the status-quo for all priors. Unlike Bewley's agents, however, VEA agents have complete preferences and compare prospects that dominate the endowment using the minimizing prior.

<sup>6</sup>I use the term "effective beliefs" to refer to the minimizing prior.

ance based on a village rain gauge, crop insurance based on a region average yield, livestock insurance based on an index of vegetation cover,<sup>7</sup> and home equity insurance based on an index of local home prices.<sup>8</sup> Proponents of index insurance claim that it is not subject to moral hazard and adverse selection and enables firms to insure risks that are subject to information asymmetries. Recent trials of index insurance have, however, garnered little demand (Cole et al. 2010 & Goetzmann et al. 2003). As Maggie's example shows, ambiguity aversion provides a potential explanation for the lack of demand.

I model households with VEA preferences in a setting where index insurance is available for a new crop and is used to encourage adoption of that crop. Technology adoption is a particularly interesting context in which to study ambiguity. First, because the technology is new, there is likely ambiguity about its production function. Second, caution implies that a household with VEA preferences can simultaneously not adopt a new technology because it is risky, and also not take out insurance to cover that risk. I use the model to show that, when there is sufficient ambiguity about the production function of the new technology, ambiguity averse (AA) households will not value actuarially fair insurance. Ambiguity averse households may, therefore, be uninsurable. I also derive three testable implications of the model. First, if the new production technology is sufficiently ambiguous, AA households will gain less from insurance than ambiguity neutral households. Second, the difference in the value of insurance for AA and ambiguity neutral households will be *increasing* in risk aversion and third the difference will be decreasing in experience with the new crop. The second observation follows because, like Maggie, VEA households are concerned that insurance will be risk increasing. The third implication follows from the simple intuition that ambiguity should decrease with experience.

I also adapt the model to study the insurance element of limited liability credit. I model limited liability as a minimum consumption level. For ambiguity neutral (AN) households, limited liability is a state contingent transfer. For AA households, however, limited liability acts like an insurance contract – it is costly in high income states and beneficial in low income states. To see this, consider an AA household that entertains a set of possible production functions, all of which have the same expected yield. When considering adopting the new crop without insurance, AA households concentrate their belief on a risky production function. When limited liability credit is introduced, AA households tend to believe the limited liability constraint will not bind. This means concentrating beliefs on a less risky production function, implying an insurance effect. Because insurance is less valuable than a transfer, AA households gain less from limited liability. Further, because the benefit of insurance is increasing in risk aversion, but

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<sup>7</sup>See Chantarat et al. (2009b,a).

<sup>8</sup>See, for example, Shiller and Weiss (1999).

the benefit of a transfer need not be, the differential impact of limited liability is *decreasing* in risk aversion. Finally, as with index insurance, the difference between *AA* and *AN* households is decreasing in experience.

I test these implications using two data sets that contain experimental variation in the provision of insurance. In both cases insurance was provided with the aim of encouraging the adoption of a new crop, and the impact of insurance on adoption rates provides a natural measure of the value of insurance.<sup>9</sup> The first data set comes from a rainfall insurance experiment documented in [Giné and Yang \(2009\)](#) and the second from a credit experiment documented in [Ashraf et al. \(2009\)](#). Both these data sets have experimental measures of ambiguity aversion and risk aversion, in addition to variation in the years of experience households have with the new crop. All four testable implications are supported in the data: ambiguity averse households are less likely to adopt the new crop when insurance is bundled with the offer of technology; this effect is stronger for the risk averse when considering rainfall insurance; weaker for the risk averse when considering limited liability; and decreasing in years of experience for both cases. Furthermore, if a researcher does not account for ambiguity aversion, households measured to be risk averse have a lower value for rainfall insurance. Controlling for ambiguity aversion and its interaction with risk aversion, this result is reversed. Among ambiguity neutral households the value of rainfall insurance is increasing in risk aversion. Among *AA* households, however, the converse is true.<sup>10</sup>

The different effect of risk aversion in the two settings is important. A possible explanation for the Malawi results is that households measured to be ambiguity averse have constant optimistic beliefs.<sup>11</sup> This possibility could explain the results for index insurance, but is not consistent with the results for limited liability. If *AA* households were merely optimistic, limited liability would not act like insurance and there would be no impact of risk aversion.

As a second application, I study the implications of VEA preferences for optimal informal risk sharing. A starting point for discussing imperfect risk sharing is Townsend's (1994) finding that, after controlling for household fixed effects and village aggregate income, household consumption is correlated with household income. This finding is not consistent with Pareto optimal risk sharing when households have the same preferences and beliefs. I show that the correlation is, however, consistent with Pareto optimal risk sharing when households have iden-

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<sup>9</sup>The model provides assumptions under which the change in adoption rates caused by the introduction of insurance is proportional to households willingness to pay for partial insurance.

<sup>10</sup>These results hold for the [Giné and Yang \(2009\)](#) data. The theory does not imply this result for the [Ashraf et al. \(2009\)](#) data and it is not true in that context.

<sup>11</sup>While possible it seems unlikely that optimism is correlated with choosing the ambiguous urn in the Ellsberg example, which is the measure of *AA* used in the empirical work.

tical VEA preferences.

A simple example provides the main intuition. Consider a VEA household (the Jones's) contemplating a risk sharing contract. The contract will specify a set of states in which the Jones's make a transfer, and a set of states in which they receive a transfer. These transfers will move the household away from its endowment, and the Jones's will tend to believe that states in which they receive a transfer are relatively unlikely, while states in which they give a transfer are relatively likely.<sup>12</sup> Relative to the optimal with fixed beliefs, the Jones's will be willing to accept a little less when receiving a transfer, in return for a little more when they are making a transfer. Hence, the optimal allocation lies closer to the endowment point than it would in the absence of ambiguity, implying that consumption will be correlated with income even after controlling for individual fixed effects and the aggregate endowment.

I formalize this intuition and ask whether the resulting theory has testable implications for panel data containing measures of household income and consumption. The full risk sharing test of Townsend (1994) uses the fact that households with the same beliefs will trade to the same point (after controlling for Pareto weights).<sup>13</sup> With VEA preferences, not all households have the same effective beliefs and formulating a similar test requires that the researcher be able to infer beliefs from a data set that does not include all households or all states of the world. The motivational example suggests one approach. In the example, the set of households making transfers in a particular state assign similar probabilities to that state, as do the set of households receiving transfers. I show that if a symmetry condition is satisfied – roughly symmetry requires that all households believe that ambiguity and income are evenly distributed around their entitlement as given by their Pareto weight – then all households making (receiving) transfers in a particular state will have the same effective beliefs, implying that they trade to the same point. I also show that the differences in beliefs between giving and receiving households creates a wedge between their consumption levels, with those giving transfers consuming more than those receiving transfers. Symmetry then implies that households whose incomes fall inside this wedge do not trade, instead consuming their own income.

Empirically, these observations imply that, in any state, households with income sufficiently above (below) their entitlement point will share risk fully.<sup>14</sup> Among these households consumption should not be correlated with income. For those households whose income falls in

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<sup>12</sup>VEA households have a set of beliefs that are valid at all times, and these do not change. In this example I use the term belief to refer to the belief within the set of beliefs that minimizes the gain from departing from the endowment. This is formally incorrect but helps with intuition.

<sup>13</sup>With equal Pareto weights an interior optimum requires that  $p_s^i u'(c_s^i) = p_s^j u'(c_s^j)$  for all pairs  $i, j$  and in all states  $s$ . If the utility functions are identical and strictly concave and  $p_s^i = p_s^j$ , this equation can only hold if  $c_s^i = c_s^j$ .

<sup>14</sup>The entitlement point can be thought of as the complete risk sharing outcome for that particular household.

the “wedge” between these two consumption levels, consumption moves one for one with income. I propose a test for these properties using a non-linear least squares routine that allows for estimation of households fixed effects, village fixed effects and the “wedge” created by ambiguity. I implement the test on two panel data sets. The famous ICRISAT data from India which formed the basis for Townsend’s (1994) paper and Townsend’s Thai monthly survey data, a 10 year panel data set. I do not reject the model in either of these settings.

Overall, the results imply that ambiguity aversion is an empirically important constraint on trade and a source of misallocation. The findings also have several policy implications. With respect to index insurance, the results suggest that insurance contracts will be subject to low demand, particularly in settings where the production technology is not well known. Thus index insurance is not the panacea that proponents may have hoped and is particularly poorly suited to encouraging technology adoption, unless combined with policies aimed to encourage learning. The results also suggest a means for finding households that are hard to insure and imply it would be useful to study methods of overcoming ambiguity aversion among households. For example, short term subsidies of new technologies may allow for learning and make insurance more effective, and marketing methods that attempt to alter the status-quo may help generate demand among the ambiguity averse (see for example, [Roca et al. 2006](#)). With respect to risk sharing, the results imply that a finding of “imperfect risk sharing” – i.e. a failure of Townsend’s (1994) test – is possible even in the absence of incentive problems within the community. This in turns implies that formal insurance need not crowd out informal insurance and improves the case for outside provision of formal finance.

The remainder of the paper is structured as follows. Section 1.2 provides some discussion of ambiguity aversion. It can easily be skipped by readers familiar with the Ellsberg paradox and the notion of ambiguity. Section 1.3 formally defines VEA preferences and discusses their relation to other preferences in the literature. Section 2 contains my study of index insurance and Section 3 discusses optimal risk sharing with VEA preferences.

## 1.2 Ambiguity Aversion

The literature on ambiguity aversion distinguishes between two types of uncertainty. A situation is risky if it is uncertain and the probabilities of different states of the world are known, it is ambiguous if it is uncertain and the probabilities are unknown. According to the Subjective Expected Utility (SEU) theory of [Savage \(1972\)](#) this distinction has no interesting implications – decision makers should assign a subjective prior to all events and maximize expected utility

using that prior. [Ellsberg \(1961\)](#), however, showed that decision makers do tend to differentiate between risky and ambiguous situations. The Ellsberg Paradox demonstrates:

**Example 1** (Ellsberg's Paradox). *There are two urns, a risky urn and an ambiguous urn. The risky urn contains 5 white and 5 black balls. The ambiguous urn contains 10 white or black balls with the ratio unknown. A decision maker is asked to choose a color and an urn. A ball will then be drawn from the chosen urn and if it is the chosen color the decision maker will win \$1.*

[Ellsberg \(1961\)](#) observed that faced with this choice many individuals strictly prefer the risky urn. Ellsberg's observation cannot be reconciled with Subjective Expected Utility maximization. An SEU maximizer assigns a probability  $p$  to the event that a black ball will be chosen from the ambiguous urn. If  $p > 0.5$  she should choose the ambiguous urn and the black ball. If  $p < 0.5$  she should choose the ambiguous urn and the white ball and if  $p = 0.5$  she should be indifferent between the two urns. Therefore there does not exist a  $p$  such that she strictly prefers the risky urn.

The Ellsberg paradox can, however, be rationalized by beliefs that exhibit choice dependent caution. An agent displays CDC if the probability distribution she uses depends on the choice that she is considering and is chosen so as to make that choice unfavorable. In the choice above the paradox is avoided if probability  $p$  depends on the color chosen. For example, the behavior can be explained if  $p = 0.4$  when black is chosen and  $p = 0.6$  when white is chosen.

### 1.3 VEA Preferences

I assume that households make use of a production technology leading to an endowment (or status-quo)  $\omega_i$  that specifies an element of  $\mathbb{R}$  for each state  $s$  in some state space  $S$ .<sup>15</sup> Households have preferences  $\succeq_i$  over consumption bundles  $c_i$ , which specify an element of  $\mathbb{R}_+$  for each  $s \in S$ . I assume that these preferences can be represented by

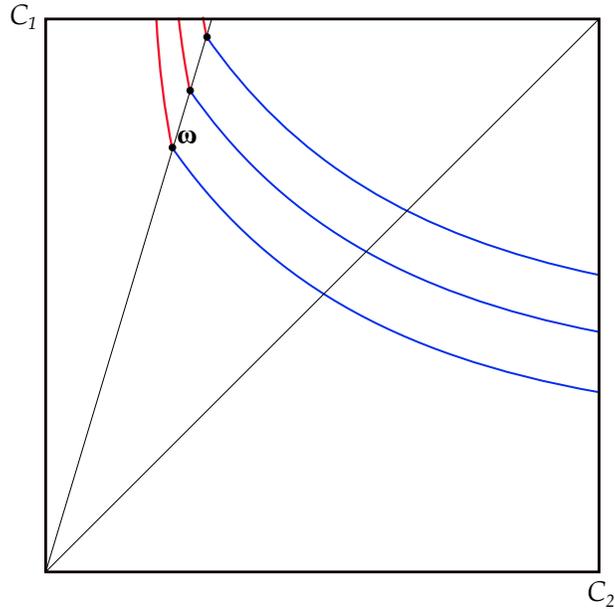
$$U(c) = \min_{\pi \in \Pi} \sum_{s \in S} \pi_s \left( u(c_s) - u(\omega_s) \right), \quad (1.1)$$

where  $u$  is a strictly concave, twice continuously differentiable, real valued function and  $\Pi$  is some closed convex set of priors in  $\Delta$ , the set of possible priors over  $S$ .<sup>16</sup> Figure 1.1 shows the indifference curves generated by 1.1 when there are two possible states and  $u = \ln$ . The key

<sup>15</sup>I assume throughout the paper that all sets are finite.

<sup>16</sup>The interpretation is that  $c \succeq c'$  iff  $U(c) \geq U(c')$ .

Figure 1.1: Indifference Curves for VEAP Preferences



observation is that the indifference curves are kinked along a ray through the origin and the endowment point.

The preferences represented by Equation (1.1) belong to the class of variational preferences axiomatized by [Maccheroni et al. \(2006\)](#).<sup>17</sup> They are also related to the classic treatments of ambiguity by [Gilboa and Schmeidler \(1989\)](#) and [Bewley \(1986\)](#). In particular, if there is no ambiguity regarding the endowment – in this case if  $\omega$  is constant in  $S$  – then (1.1) collapses to the maxmin model of Gilboa and Schmeidler. On the other hand (1.1) represents one way of choosing among alternatives that dominate the status-quo but would be incomparable in Bewley’s model of incomplete preferences.

As with all examples of variational preferences, the preferences in (1.1) can be given a simple psychological interpretation. When considering making a decision with only limited information, the agent behaves as if she is playing a game against a malevolent agent (nature) who is able to alter  $\pi$ .<sup>18</sup> In the case of (1.1), the malevolent nature chooses  $\pi$  from within the set  $\Pi$  with

<sup>17</sup>To the best of my knowledge, these preferences appear only one other time in the literature. [Dana and Riedel \(2010\)](#) use these preferences to provide a proof of the existence of equilibrium in a dynamic economy where agents have [Bewley \(1986\)](#) preferences. Dana and Riedel refer to the preferences in (1.1) as “variational utility anchored at  $\omega$ ” and argue that the preferences fulfill the axioms for variational preferences.

<sup>18</sup>For some neuroscientific evidence consistent with this interpretation see [Hsu et al. \(2005\)](#).

the aim of making the decision to depart from the endowment as bad as possible. Given the relation to variation preferences and the role played by the endowment I refer to the preferences in (1.1) as Variational Endowment Anchored (VEA) preferences.

VEA households display Choice Dependent Caution (CDC). In considering a move to a new allocation  $c$  a VEA household's minimizing prior  $\pi(c) \in \Pi$  depends on  $c$  – hence choice dependent. Further,  $\pi(c)$  is chosen in a manner that is cautious – favoring the endowment over  $c$ . It is this choice dependence that leads to interesting implications with respect for insurance. At its most simple level, the claim of this paper is that households that exhibit CDC will be hard to insure because whatever an insurance contract specifies, a VEA household will tend to believe that it is unlikely to payout.

Choice dependence also allows VEA preferences to rationalize the Ellsberg Paradox presented in Example 1 above. Specifically, when considering choosing the ambiguous urn and the white ball VEA households will worry that black balls are relatively common. On the other hand, when considering choosing the ambiguous urn and the black ball the same household will worry that white balls are relatively common. Formally let  $\pi \in \Pi$  be the perceived probability of drawing a white ball. If the status-quo is not subject to uncertainty, or the risky urn is the status quo then so long as  $\Pi \supset \{0.5\}$  a VEA household will choose the risky urn over the ambiguous urn.

The choice of VEA preferences, rather than some other model of ambiguity, is largely driven by the application to risk sharing in Part 3 of the paper. It is well known that the MEU preferences of Gilboa and Schmeidler (1989) tend to increase the benefit to mutual insurance, while the preferences of Bewley (1986) reduce the likelihood of trade in a Edgeworth box economy (see Bewley 1989 and Rigotti and Shannon 2005). VEA preferences capture this implication of Bewley preferences, but make more specific predictions regarding optimal contracts. This specificity is required to give empirical content to the model. When I consider index insurance in Part 2 of the paper I assume that there is a modern and a traditional crop that the household must choose from. The traditional crop is the status-quo, but is not subject to ambiguity. Following the discussion above this implies that VEA preferences have the same implications as the MEU model of Gilboa and Schmeidler (1989). With this as background I now turn to the two applications.

## 2 Index Insurance and Ambiguity

### 2.1 Outline of Argument

In this part of the paper I argue that choice dependent caution has important implications for index insurance contracts. While index insurance may solve the asymmetric information problem, it has one feature that reduces its value for ambiguity averse households. The payout from index insurance is not perfectly correlated with income. Even if the index itself is not ambiguous, which may be the case for rainfall, there is likely ambiguity surrounding the production technology (i.e. the mapping from the index to income). When considering whether to acquire insurance, household that exhibit CDC will concentrate their beliefs on production functions that imply the insurance is risk increasing. For example, when considering rainfall insurance the household will tend to believe that yield is negatively correlated with rainfall, just as in Maggie's example in the introduction. Therefore, for households that are both risk averse and ambiguity averse, the insurance will not be valuable.

It is important to note that this implication is not specific to a particular insurance contract, but applies to all insurance contracts so long as the set of beliefs entertained by the AA agent is sufficiently large. It is, therefore, not simply a matter of offering a different contract. Sometimes AA agents are uninsurable (this claim is formalized in Proposition 1 Part 3 below).

I study the implications of CDC in a setting where insurance is used to encourage the take-up of new technologies. It has been argued that uninsured risk leads the poor to use low risk but low return technologies (Rosenzweig and Binswanger 1993) and delay the take-up of newer high return but potentially high risk technologies (Feder et al. 1985). In such a setting CDC operates as a double edged sword, implying that an agent can simultaneously avoid take-up *because* of risk, but be unwilling to accept insurance that mitigates the risk. Example 2 illustrates this possibility.

**Example 2** (A Double Edged Sword). *An AA agent must decide between two technologies. The traditional technology gives a certain return of  $\$(1 - \epsilon)$  while the modern technology is risky and ambiguous. There are two possible states of the world L (for low rain) and H (for high rain) and it is assumed that both are known to be equally likely. The agent believes that the modern technology may have one of two production functions:  $\theta_1$  which gives \$0 in state L and \$2 in state H and  $\theta_2$  which gives a certain income*

of \$1. Thus the AA agent believes that the new technology has a higher return. In the absence of insurance, caution (along with risk aversion) implies the AA household believes  $\theta_1$  is the true mapping and (for suitable  $\epsilon > 0$ ) will not adopt the new technology despite its having a higher expected return.

Now consider an actuarially fair insurance contract that pays out \$1 in state L and costs \$1 in state H. CDC implies that when considering the insurance contract the agent will believe that  $\theta_2$  is the true mapping and that the insurance contract is actually risk increasing. Insurance will therefore not encourage adoption. Thus risk constrains the choice of the new technology but it cannot be mitigated by the provision of a (generous) insurance contract which mitigates the risk.<sup>1</sup>

This section of the paper has two aims. First, I provide a simple model of technology adoption among households with VEA preferences and derive the theoretical implications of CDC. I place particular emphasis on the possibility that VEA households are uninsurable. Second, I test the theory using data from two randomized control trials designed to study the take-up of new technologies. The first data set is from Malawi and documents demand for a rainfall insurance product and the second is from Kenya and studies the provision of credit. Section 2.2 discusses the settings in detail and particularly addresses why credit can be thought of as a partial insurance product subject to low demand by AA households. Importantly, in both cases, the technology (or a precursor to it) had been available for some time and some farmers had experience with it. Further, both data sets have measures of risk aversion and ambiguity aversion.<sup>2</sup> The experimental nature of the data sets implies that the impact of insurance on demand for the new crop is well identified. I use changes in demand for the new crop as a natural measure of the value of insurance.

Beyond uninsurability, the main implication of the theory for insurance demand is that relative to an ambiguity neutral (AN) household, an AA household that has similar beliefs in the absence of insurance will gain less from insurance (Proposition 1 Part 2). Beliefs are, however, not observable and consequently this implication is not directly testable. My empirical strategy is therefore to look for the stronger implication that AA agents benefit less from insurance than AN agents (Proposition 3.3 Part 1 shows that this will be the case if the situation is sufficiently ambiguous). Assuming that caution in the absence of insurance implies that insurance is valuable (in the sense that it will increase demand for the new crop), observing that AA agents benefit less from insurance implies CDC (Proposition 3.3 Part 2).

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<sup>1</sup>It is also possible to show that the impact of insurance is limited regardless of the specifics of the contract. Suppose that the contract provides \$ $x$  in state L and costs \$ $x$  in state H. The optimal contract for the ambiguity averse agent is  $x = 0.5$ , while for an ambiguity neutral agent who is concerned by risk the optimal contract is  $x = 1$ . Thus regardless of the insurance contract it is less effective for the AA agent.

<sup>2</sup>I discuss the measures in more detail in Section 2.4.3.

Both data sets strongly support the hypothesis that *AA* households benefit less from insurance.<sup>3</sup> Beyond this, the theory has three further testable implications. First, the beliefs of *AA* and *AN* agents will tend to converge as the agents learn about the new technology (Marinacci 2002 & Epstein and Schneider 2007). Consequently, if learning is fastest when the farmer grows the crop himself, the disparity in demand for insurance between *AA* and *AN* agents will tend to decrease as experience with the new technology increases. I show that this implication holds for both data sets. Second, for index insurance, the model implies that the negative effect of CDC on take-up is stronger for households that are risk averse. An increase in risk aversion implies that insurance is more valuable for *AN* households, but increases the fear that the insurance is risk increasing for *AA* households. This surprising implication also holds in the Malawi data. Interestingly, if this second implication is ignored it appears that risk aversion is not correlated with demand for insurance. After accounting for this effect, however, measures of risk aversion behave as theory predicts – demand for insurance is increasing in risk aversion among *AN* households and decreasing among *AA* households.<sup>4</sup> Third, for limited liability credit, the model implies that the negative effect of CDC on take-up is stronger among risk tolerant households. This implication holds in the Kenya data.

The model has several policy implications. First, index insurance is more likely to be valuable in situations where production techniques and the index are well understood. For example, rainfall insurance is more likely to be successful in areas where the main crop has been cultivated for some time. Further, index insurance is not well suited to encouraging the take-up of new crops. Second, it may be possible to encourage take-up of new crops through short term subsidies for use and long term provision of insurance. Third, because ambiguity is likely to persist even in the long run (Bewley 1988, Epstein and Schneider 2007 & Al-Najjar 2009) index insurance should not be seen as a complete solution to the non-existence of insurance markets.

The remainder of the discussion on index insurance proceeds as follows. Section 2.2 discusses the data in more detail. Section 2.3 outlines a formal model of ambiguity aversion and its consequences for index insurance. Empirical implications are derived in Section 2.4 and Section 2.5 discusses policy implications. Section 2.6 presents the empirical results and section 2.7 discusses other possible explanations of the data. Finally, section 2.8 offers some conclusions.

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<sup>3</sup>This basic implication is also supported by Chantarat et al. (2009a). That study estimates the willingness to pay for a Kenyan index insurance product that aims to cover the risk of livestock death. While not the focus of the paper, the authors find that ambiguity averse households have a significantly lower willingness to pay for the product.

<sup>4</sup>This is particularly interesting given the often poor predictive power of risk aversion measures.

## 2.2 Data

### 2.2.1 Kenya

The first data set is from a Kenyan experiment that aimed to understand what prevents farmers from growing export crops. The details of the experiment are reported in [Ashraf et al. \(2009\)](#). The authors worked with DrumNet, a project of Pride Africa. Drumnet provides information, marketing and credit to encourage small scale farmers to grow export crops. A farmer who takes up the DrumNet offer receives a package of seeds for an export crop (french beans, passionfruit or baby corn) as well as assistance with marketing. The experiment consisted of several treatments, but only one is relevant for the current study: a subset of the farmers were randomly chosen to receive credit from DrumNet as well as the usual services. The data set provides information on the take-up decision, past use of the export crops and measures of risk aversion and ambiguity aversion. These measures are discussed in detail in Section 2.4.3. Ambiguity aversion and risk aversion measures are only available for 409 of 450 farmers and I restrict my analysis to these subjects.<sup>5</sup>

One may wonder why data documenting the impact of a credit intervention is relevant to a paper on insurance? If the situation is characterized by limited liability then a credit contract also provides a form of insurance. The issue is discussed in depth in the next section, but here I give some intuition. Suppose there are three states of the world (1,2,3) that are equally likely and provide income  $-1, 2$  and  $4$  respectively. A simple credit contract provides 1 unit of income and has an interest rate cost of  $r < 2$ . If income cannot fall below 0 (the limited liability constraint) then in state 1 the loan is not repaid. Therefore, this simple credit contract could be thought of one which provides a payment 1 in state 1 but  $1 - r < 0$  in states 2 and 3, and is thus an insurance contract.<sup>6</sup> All that is required for the interpretation is that farmers perceive that there is a level of yield below which the credit company cannot claim repayment.<sup>7</sup>

### 2.2.2 Malawi

The second data set comes from an experiment in Malawi designed to test the efficacy of index insurance in promoting the take-up of HYV seeds – in this case groundnut seeds. The details of the experiment can be found in [Giné and Yang \(2009\)](#). The sample consisted of 771 Malawian

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<sup>5</sup>The results are robust to considering all farmers and including dummy variables for missing data.

<sup>6</sup>That credit contracts with limited liability provide insurance is essential to the literature on moral hazard (see, for example [Stiglitz and Weiss 1981](#)).

<sup>7</sup>That is the limited liability can be implicit.

groundnut and maize farmers who were members of the National Smallholder Farmers Association of Malawi (NASFAM). These farmers were provided with the opportunity to purchase a package of HYV groundnut seeds.<sup>8</sup> The experiment randomly divided the sample into treatment and control and treatment farmers were *required* to take-up rainfall insurance in addition to the seeds. Details of the insurance product can be found in [Giné and Yang \(2009\)](#), but the essential ingredient is that it is an index insurance product paying out an amount which depends on rainfall measured at a village rainfall gauge. The insurance was also intended to be actuarially fair with the calculation based on historic rainfall data. In order to recoup costs, however, a lump sum additional payment was required.

The data set includes measures of take-up of the new crop, experience with groundnut and measures of ambiguity aversion and risk aversion for 730 of the farmers.<sup>9</sup> I concentrate my analysis on these 730 farmers.<sup>10</sup> It is worth noting that the groundnut seeds offered as part of the experiment were a new HYV variety that had not previously been available. The previous seasons planting of groundnut, however, consisted almost entirely of a slightly older HYV strain. There are therefore two potential sources of ambiguity: ambiguity surrounding groundnut in general and ambiguity surrounding the new HYV seeds. Because no farmers reported using the new HYV seeds before the experiment it is not possible to assess the impact of learning with respect to the second form of ambiguity. However, a measure of experience with groundnut captures learning with respect to the former. It is unclear whether ambiguity regarding each new HYV strain is important or whether farmers tend to treat strains as similar. Either way, the model presented below suggests that both factors should be relevant and that learning with respect to groundnut in general should lead to diminished impact of ambiguity aversion.

### 2.2.3 Summary Statistics

Tables [2.1](#) and [2.2](#) provides some basic summary statistics for the two data sets. The columns present the means of each variable within the ambiguity neutral (*AN*) and ambiguity averse (*AA*) groups. Orthogonality with respect to the treatment is established in each of the respective papers. The main take-away point from Tables [2.1](#) and [2.2](#) is that measured ambiguity aversion is not correlated with many household characteristics, making the strong correlation between ambiguity aversion and insurance demand more surprising.

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<sup>8</sup>The offer also included the option to purchase HYV maize seeds, but this offer was rarely taken up.

<sup>9</sup>The method for eliciting risk and ambiguity preference is discussed in Section [2.4.3](#).

<sup>10</sup>The results are robust to considering all farmers and including dummy variables for missing data.

Table 2.1: Summary Statistics: Malawi

	<i>AN</i>	<i>AA</i>	<i>p-Value</i>
<i>Respondent Age</i>	40.377 (13.100)	40.492 (12.467)	0.904
<i>Head Female</i>	0.119 (0.325)	0.121 (0.327)	0.949
<i>Years Schooling Head</i>	5.107 (3.427)	5.450 (3.678)	0.198
<i>House Quality</i>	-0.050 (1.247)	0.015 (1.293)	0.495
<i>Land Holding</i>	7.345 (8.235)	7.114 (8.374)	0.709
<i>Total Income</i>	36.860 (215.910)	30.108 (85.823)	0.563
<i>Saving Account</i>	0.195 (0.397)	0.237 (0.426)	0.171
<i>Ever Committee Member</i>	0.472 (0.500)	0.419 (0.494)	0.154
<i>Experience Gnut</i>	9.110 (8.743)	8.074 (8.168)	0.101
<i>Correct Insurance</i>	0.437 (0.497)	0.414 (0.493)	0.532
<i>Risk Tolerance</i>	3.808 (1.926)	3.554 (2.083)	0.092*
<i>Trust Insurance</i>	0.003 (0.056)	0.002 (0.049)	0.853
<i>Trust Finance</i>	5.963 (2.440)	5.909 (2.555)	0.775
<i>Trust Gauge</i>	5.770 (3.530)	5.660 (3.379)	0.685
<i>Trust General</i>	0.346 (0.338)	0.305 (0.329)	0.101
<i>N</i>	318	413	
<i>Distance to Gauge</i>	11.274 (12.733)	12.339 (14.439)	0.497
<i>Missing Dist to Gauge</i>	0.594 (0.492)	0.530 (0.500)	0.084*
<i>N</i>	129	194	

\*\*\*  $\Rightarrow p < 0.01$ , \*\*  $\Rightarrow p < 0.05$ , \*  $\Rightarrow p < 0.1$ . Standard deviations in parentheses. *p*-values are for a *t*-test of the hypothesis that the mean value does not depend on measured ambiguity aversion. Correct insurance indicates a household was able to answer a hypothetical question about the insurance contract. Trust measures are of the form "On a scale of 1 - 10 how much do you trust...". Committee member refers to NASFAM.

Table 2.2: Summary Statistics: Kenya

	<i>AN</i>	<i>AA</i>	<i>p-Value</i>
<i>Age Member</i>	40.980 (11.743)	41.466 (12.956)	0.698
<i>Respondent Female</i>	0.450 (0.499)	0.408 (0.493)	0.406
<i>Head Female</i>	0.083 (0.276)	0.050 (0.218)	0.181
<i>Years School Head</i>	6.218 (1.919)	6.175 (1.947)	0.824
<i>Literate Member</i>	0.781 (0.415)	0.858 (0.349)	0.042**
<i>House Quality</i>	1.394 (0.822)	1.281 (0.922)	0.206
<i>Land Area</i>	1.800 (1.739)	1.930 (1.734)	0.457
<i>Saving Account</i>	0.696 (0.460)	0.675 (0.469)	0.659
<i>Ever Officer</i>	0.160 (0.367)	0.200 (0.401)	0.302
<i>Log Income</i>	3.340 (1.296)	3.372 (1.278)	0.807
<i>Yield Past Year</i>	25.587 (45.061)	25.309 (43.335)	0.950
<i>years With Shg</i>	49.107 (40.520)	47.862 (35.533)	0.836
<i>Distance to Road</i>	0.955 (1.474)	0.773 (1.269)	0.187
<i>Optimism</i>	2.650 (1.635)	2.355 (1.497)	0.059*
<i>Impatient</i>	0.160 (0.367)	0.146 (0.354)	0.700
<i>N</i>	169	240	

\*\*\*  $\Rightarrow p < 0.01$ , \*\*  $\Rightarrow p < 0.05$ , \*  $\Rightarrow p < 0.1$ . Standard deviations in parentheses. *p*-values are for a *t*-test of the hypothesis that the mean value does not depend on measured ambiguity aversion. Member refers to the household member of NASEFAM. SHG refers to the self help groups that were used to distribute seed. Officer refers to an officer of the SHG. Optimism is a self reported measure of optimism. Impatient is an indicator for having above median discount rate in a hypothetical time preference question.

## 2.3 A Model of Technology Adoption with VEA Preferences

In this section I introduce a simple model of technology adoption when households have VEA preferences. I use the model to analyze the impact of insurance on demand for the new technology. The analysis in this section applies to index insurance contracts such as the rainfall insurance introduced in Malawi by [Giné and Yang \(2009\)](#). Section 2.4 derives testable implications of the theory and in that section I indicate how the model can be adapted to apply to limited liability credit.

The model has implications for the probability that a household will adopt the new technology, and the impact of insurance on that probability. Regarding adoption, the model implies that among otherwise identical households, *AA* households are less likely than *AN* households to adopt. This implication holds with or without insurance and follows from the assumption that *AA* households are cautious.

The model also implies that *AA* households benefit less from insurance. I show two specific implications. First, given pre-insurance beliefs,<sup>11</sup> adoption rates for *AA* households increase less in response to insurance. Second, households that are sufficiently ambiguity averse are uninsurable in the sense that no actuarially fair insurance contract increases the rate of adoption. This implication holds even in a context where *AA* households perceive the new technology to be risky. When insurance is compulsory, in the sense that it is required to adopt, uninsurability implies that actuarially fair insurance can reduce the rate of adoption, an implication that is particularly relevant given the finding in [Giné and Yang \(2009\)](#) that compulsory rainfall insurance decreased adoption rates.

In the model there is a strong relationship between the impact of insurance on adoption and the value of insurance. Specifically, the increase in adoption is proportional to the amount of money that a household would pay for the insurance contract. This measure is simply the risk premium for the partial insurance problem as in [Ross \(1981\)](#). The uninsurability result, therefore, implies that if a household is sufficiently ambiguity averse, they will be unwilling to pay a positive amount for any rainfall insurance contract.

The uninsurability result has important implications for the ability of insurance to help encourage technology adoption. In particular it implies that an *AA* household can *simultaneously* not adopt a new technology *because* of risk, and not demand insurance that would mitigate that risk. The result, however, also applies to the more general question of demand for insurance when there is no new technology under consideration. In that context, so long as the crop un-

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<sup>11</sup>As discussed above pre-insurance are the beliefs in the set  $\Pi$  which minimize the benefit of adopting the new technology when insurance is not available.

der production has an ambiguous technology, households that are sufficiently ambiguity averse will not benefit from index insurance.

### 2.3.1 Preferences, Technology Adoption and the Value of Insurance

Consider a sample of households choosing between two technologies, a modern crop  $M$  and a traditional crop  $T$ . The output of the two technologies is dependent on the level of rainfall  $r \in R$  and all households agree that the probability of rainfall level  $r$  is  $p(r)$ .<sup>12</sup>

The traditional technology is the status-quo and I assume that households receive expected utility from the traditional technology

$$Eu^T = \alpha + \eta,$$

where  $\alpha$  is the mean expected utility from the crop and  $\eta \sim U[-\bar{\eta}, \bar{\eta}]$  is a household specific characteristic that determines the profitability of the traditional crop. This formulation of the return to the traditional crop allows for it to be dependent on rainfall, but not ambiguous.

The modern crop is characterized by ambiguity. The production function for the modern crop is a map  $\theta : R \rightarrow \mathbb{R}_+$  and households believe that this map is chosen from some set  $\Theta$ . I assume that households have limited information regarding which  $\theta$  is most likely and therefore have a *set* of priors  $\mathcal{C}$  over  $\Theta$ . A single prior  $\mu \in \mathcal{C}$  assigns a probability  $\mu(\theta) \in [0, 1]$  to each possible production function in  $\Theta$ . I denote  $\mathcal{C}^A$  the set of priors of a household measured to be ambiguity averse and  $\mathcal{C}^N$  the set of priors of a household measured to be ambiguity neutral. I assume throughout that  $\mathcal{C}^N$  is a strict subset of  $\mathcal{C}^A$ . This model captures a situation where the rainfall distribution is not ambiguous, but the mapping from rainfall to output is ambiguous for the modern crop.<sup>13</sup>

I restrict my analysis to the case in which all priors are degenerate.<sup>14</sup> That is, all  $\mu \in \mathcal{C}$  place probability 1 on some production function  $\theta$  and 0 on all others. In this context I denote  $\Theta^A$  the set of production functions for which  $\mu(\theta) = 1$  for some  $\mu \in \mathcal{C}^A$  and  $\Theta^N$  is similarly defined. I assume throughout that  $\Theta^N$  is a singleton denoted  $\theta^N$ . This setting is sufficiently rich to highlight the impact of ambiguity on choices and leads to easier more intuitive derivations. I also assume that all production functions in  $\Theta^A$  have the same expected yield. This assumption seems reasonable as villagers are likely informed of average yields by extension agents, it is the riskiness of the yield that is uncertain.

<sup>12</sup>All sets referred to in the model are assumed discrete and finite.

<sup>13</sup>See [Giné et al. \(2007\)](#) for evidence that farmers are well informed regarding the rainfall distribution.

<sup>14</sup>Appendix [C](#) discusses the more general case.

In this context, an insurance contract is a mapping  $\gamma : R \rightarrow \mathbb{R}$  which assigns to each rainfall state a (not necessarily positive) transfer from the insurance company to the household. An insurance contract is actuarially fair if  $\sum_{r \in R} p(r)\gamma(r) = 0$ . With insurance available, a household with  $\eta = \hat{\eta}$  adopts the new crop if

$$\min_{\theta \in \Theta} \sum_{r \in R} p(r)u(\theta(r) + I\gamma(r)) \geq \alpha + \hat{\eta}, \quad (2.1)$$

for  $I = 0$  or  $I = 1$ . If insurance is not available the household adopts if (2.1) holds with  $I = 0$  and if insurance is compulsory the household adopts if (2.1) holds for  $I = 1$ .

In the absence of heterogeneity other than  $\eta$ , equation (2.1) defines  $\tilde{\eta}^A$  and  $\tilde{\eta}^N$ , cutoff points below which  $AA$  and  $AN$  households adopt the new technology. I denote  $\tilde{\eta}(NI)$ ,  $\tilde{\eta}(CI)$  and  $\tilde{\eta}(I)$  as the cutoff values of  $\eta$  in the case of no-insurance, compulsory insurance and optional insurance respectively.

With this notation I define the value of optional insurance to  $AA$  households to be the density of  $AA$  households motivated to adopt the new crop because of the insurance:

$$V^A(I) = \frac{\tilde{\eta}^A(NI) - \tilde{\eta}^A(I)}{2\tilde{\eta}}. \quad (2.2)$$

The value of insurance in other cases and to other groups,  $V^N(I)$ ,  $V^A(CI)$  and  $V^N(CI)$  are defined analogously. This measure of value is closely related to the risk premium. In particular, implicitly define the risk premium  $\pi(\Theta, \gamma)$  to be the value such that

$$\min_{\theta \in \Theta} \sum_{r \in R} u(\theta(r) - \pi(\Theta, \gamma)) = \min_{\theta \in \Theta} \sum_{r \in R} u(\theta(r) + \gamma(r)),$$

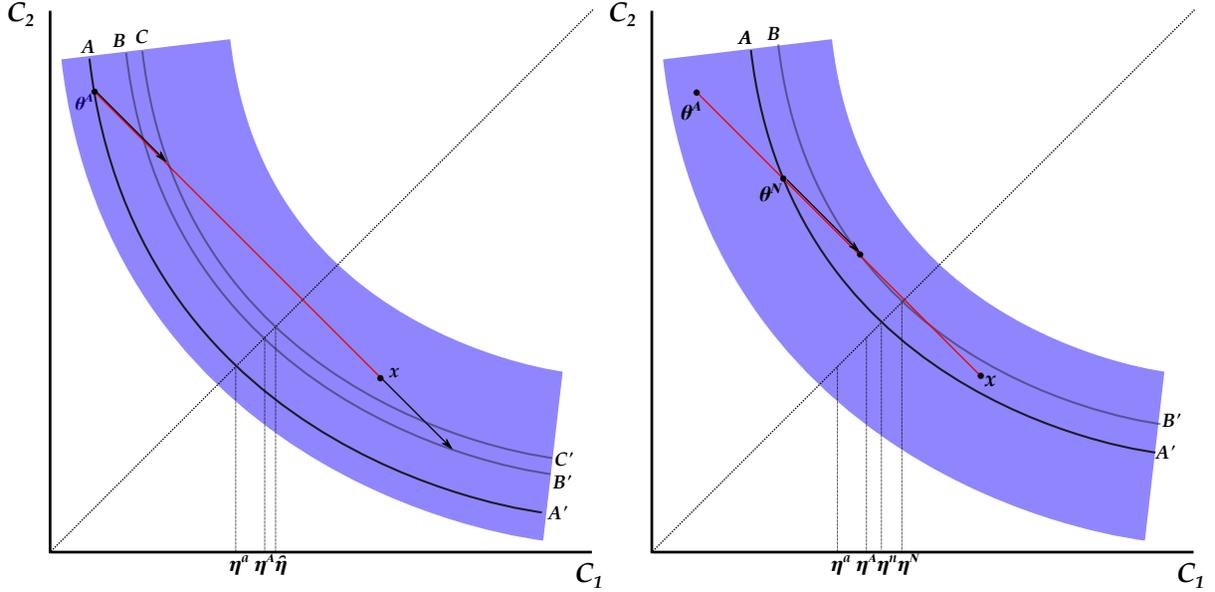
then  $\pi(\Theta, \gamma) = \tilde{\eta}(NI) - \tilde{\eta}(I)$  with the implication that the value of insurance  $V^A(I)$  is proportional to the risk premium.

### 2.3.2 A Two State Example

I illustrate the main implications of the model in a very simple setting with two rainfall states. Appendix C considers the extension of the results of this section to the more general setting. Figures 2.1 and 2.2 illustrate the main theoretical implications of the model. In the diagrams the  $x$  and  $y$  axes show consumption in the low rain state and consumption in the high rain state respectively.

I first show that ambiguity averse households are less likely to adopt, either with or without

Figure 2.1: Takeup for Ambiguity Averse and Ambiguity Neutral Households



insurance. Consider first Figure 2.1. In both panels the red line  $\theta^A x$  represents the set  $\Theta^A$ , the black arrows represents an actuarially fair insurance contract and the shaded area represents the set of possible indifference curves as  $\eta$  changes. The assumption that all production functions have the same expected yield implies that an actuarially fair insurance contract is collinear with the set  $\Theta^A$ . The left panel shows the choice for ambiguity averse households. Throughout the analysis I use  $\theta^A$  to denote the solution to

$$\operatorname{argmin}_{\theta \in \Theta^A} \sum_{r \in R} p(r) u(\theta(r)), \quad (2.3)$$

and I refer to the belief  $\theta^A$  as the “beliefs without insurance” or “pre-insurance beliefs”. For AN households pre-insurance beliefs and beliefs are obviously the same.

Indifference curve  $AA'$  shows expected utility in the absence of insurance and indifference curve  $BB'$  expected utility with optional insurance.  $AA$  households with  $\eta < \eta^a$  adopt the new technology in the absence of insurance, and households with  $\eta < \eta^A$  adopt with insurance. The indifference curves are similarly labeled in the right panel for the AN households. Households with  $\eta < \eta^a$  will adopt without insurance and  $\eta < \eta^N$  with insurance. The assumption that  $\theta^N \in \Theta^A$  immediately implies that  $\eta^A \leq \eta^N$  and  $\eta^a \leq \eta^N$  implying that AA households are less

likely to adopt the new technology either with or without insurance.

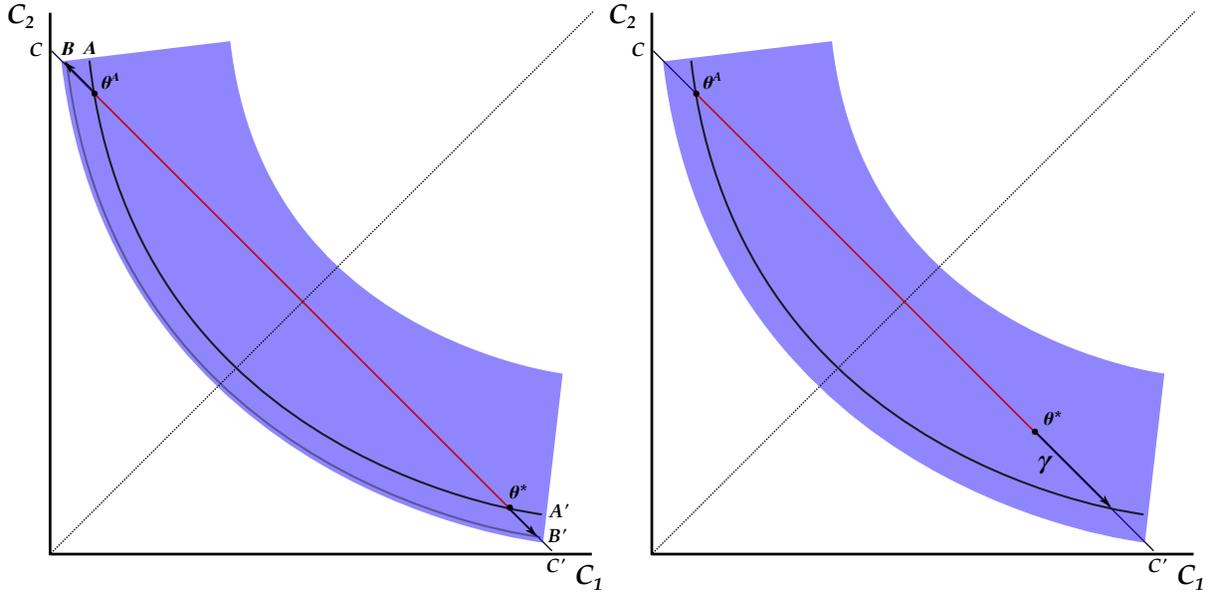
The left panel of Figure 2.1 also shows that conditional on pre-insurance beliefs, insurance is less valuable to the *AA* households. In particular suppose that in addition to being the solution to (2.3),  $\theta^A$  is the singleton belief of the *AN* households. In the diagram the value of the insurance for the *AA* household is  $(\eta^A - \eta^a)/2\bar{\eta}$ , while the value for the *AN* household is  $(\hat{\eta} - \eta^a)/2\bar{\eta}$  implying that the value of the insurance to the *AA* household is weakly less than for the *AN* household. This implication follows more generally because if indifference curve  $CC'$  is to the left of indifference curve  $BB'$ , then the minimizing beliefs with insurance will be  $\theta^A$  and both *AN* and *AA* households will benefit equally. On the other hand, if indifference curve  $BB'$  is to the left of  $CC'$  (as it is in the diagram) then the *AA* households will change beliefs when considering the insurance and the propensity to benefit from insurance will be lower.

Figure 2.2 illustrates the results on uninsurability. Consider first the left panel. In that diagram, all actuarially fair insurance contracts can be represented as arrows moving along the line  $CC'$ . The definition of  $\theta^A$  is as above. Suppose that in addition to  $\theta^A$  the set  $\Theta^A$  also includes  $\theta^*$ , then all actuarially fair insurance contracts will have zero value to the ambiguity averse household (insurance contracts that move north-west along  $CC'$  are risk increasing when beliefs are  $\theta^A$ , implying that minimal utility is given by indifference curve  $BB'$  and insurance contracts that move south-east are risk increasing when beliefs are  $\theta^*$  with a similar implication). The simple point is that if the set of beliefs  $\Theta^A$  is such that the household cannot rule out the possibility that a given contract is risk increasing, then that contract will have zero value.

Four points should be noted about the uninsurability result. First, the result holds despite the fact that the *AA* households perceive the modern crop to be risky. This is illustrated by the fact that  $\theta^A$  is not on the certainty line. As discussed above, this implies that *AA* households can simultaneously be deterred from adopting because of risk, but also not demand insurance to mitigate that risk. Second, the majority of insurance contracts require some kind of minimum purchase. In the diagram this is a minimum length of the insurance arrow. The size of the set  $\Theta^A$  required for a household to be uninsurable is decreasing in the minimum purchase requirement. This fact is illustrated in the right panel of Figure 2.2 where once again  $\theta^A$  is the minimum of the set  $\Theta^A$ . Suppose that the minimum insurance level is indicated by the length of the arrow  $\gamma$ . If this is the case then uninsurability requires that  $\theta^*$  be in the set  $\Theta^A$ . It is easy to see that as  $\gamma$  increases  $\theta^*$  moves north-west and the set  $\Theta^A$  shrinks.

Third, with only two rainfall states the uninsurability result seems unsurprising. With more rainfall states, however, the result is more surprising. One common explanation for low demand for rainfall insurance is basis risk. Because rainfall on a particular plot is not perfectly correlated

Figure 2.2: Ambiguity Averse Households May be Uninsurable



with rainfall measurement at the gauge there may be some states of the world in which rainfall insurance is risk increasing. This risk is termed basis risk and it implies that it is always possible to write a valuable insurance contract with a gauge that is centered on a household's particular plot.<sup>15</sup> The uninsurability result for ambiguity averse households implies that this will not be the case if there is sufficient ambiguity. Fourth, the left panel of Figure 2.2 illustrates that if the insurance is compulsory, in the sense that it is not possible to adopt the new crop without it, then insurance may have a negative value. Again this is true despite the fact that the ambiguity averse household is risk averse and believes that the new crop is risky.

Proposition 1 collects the four results from this section.

**Proposition 1** (Theoretical Implications of VEA). *If  $\theta^N \in \Theta^A$  then*

1. *Ambiguity averse households are less likely than ambiguity neutral households to adopt the new technology. This result holds either with or without insurance.*
2. *Holding constant beliefs without insurance, ambiguity averse households gain less from insurance.*

<sup>15</sup>See Doherty and Schlesinger (1990) for a related analysis.

3. *There exist  $\Theta^A$  such that all actuarially fair insurance contracts have no value (i.e.  $V^A = 0$ ). Moreover this result holds when AA households perceive the modern crop to be risky.*
4. *There exist  $\Theta^A$  such that all compulsory actuarially fair insurance contracts have negative value (i.e.  $V^A < 0$ ). Again this result holds when AA households perceive the modern crop to be risky.*

## 2.4 Empirical Implications

Proposition 1 provides the main theoretical implications of the model. None of those implications are, however, directly testable. In particular, testing Part 1 requires controlling for all other characteristics of the households that might be correlated with ambiguity aversion and testing Part 2 would require knowledge of households beliefs. A direct test of Parts 3 and 4 seems to require offering a multitude of insurance contracts and observing demand.

Parts 2 and 3 of Proposition 1 however suggest an empirical strategy. If the set  $\Theta^A$  is sufficiently large, AA households will gain less from any insurance contract ( $V^A < V^N$ ). This implication is particularly easy to test in a setting where insurance is experimentally provided. Equation (2.2) defines the value of insurance,  $V^A$  and  $V^N$ , in terms of the increase in demand for the new crop induced by the provision of insurance. This is simply the effect of an insurance treatment on the probability of adopting the new crop. The claim that  $V^A < V^N$  can then be assessed as a heterogeneous treatment effect. Testing for heterogeneous treatment effects means that variables which are correlated with measured ambiguity aversion and overall demand for the new crop are controlled for (i.e.  $\alpha$  can be correlated with AA) significantly reducing the identification problem that would be encountered if one were to test Part 1 of Proposition 1.

Further, if  $V^A < V^N$  the theory has two more testable implications, both of which can be formulated as heterogeneous treatment effects. First, if the insurance contract is valuable to household with beliefs  $\theta^A$  (these are the pre-insurance beliefs defined in equation (2.3)) then finding that insurance is less valuable for those who are ambiguity averse is evidence of CDC – it must be the case that the minimizing prior is different when insurance is offered.<sup>16</sup> This in turn implies that AA households believe that the insurance is more than sufficient to overcome all risk and implies that the difference between the two treatment effects  $V^N - V^A$  should be increasing in risk aversion. Because the data I use has measures of risk aversion, this implication is testable. Finally, if the set  $\Theta^A$  converges to the set  $\theta^N$  as households learn and households learn more from their own experience than the experience of others, then the differences

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<sup>16</sup>In a setting with more states of the world this implication requires that  $\theta^A$  be more risky than  $\theta^N$  in the sense of a mean preserving monotone spread. The issue is discussed in Appendix C.

$V^N(CI) - V^A(CI)$  should be decreasing with experience.<sup>17</sup>

These are the simple implications that are tested in the empirical section of this paper. The remainder of this section is broken into two parts. First, I demonstrate more formally the empirical implications continuing with the example from section 2.3.2. Second, I consider a slight variation of the model to accommodate the limited liability credit contract offered in Kenya. I show that in that context we should expect that  $V^A < V^N$  and that this heterogeneous treatment effect should be decreasing in experience. In the context of limited liability credit, however, it is no longer the case that the heterogeneous treatment effect should be increasing in risk aversion and there is some reason to believe that it will be decreasing in risk aversion.

### 2.4.1 Empirical Implications: Malawi

I first argue that if  $\Theta^A$  is large enough,  $AA$  households will gain less from insurance ( $V^A < V^N$ ). Consider an  $AN$  household that has a prior  $\theta^N$  as in the left panel of Figure 2.3. Insurance moves this household from indifference curve  $CC'$  to  $DD'$  and the distance  $V^N$  measures the gain. Next, consider an  $AA$  household that has beliefs without insurance given by  $\theta^A$ . If  $\theta^*$  is included in the set  $\Theta^A$ , then the gain from insurance for the ambiguity averse household is given by  $V^A = V^N$ . Now consider moving  $\theta^*$  south-east. This will decrease  $V^A$  and implies that for any  $\theta^N$  and  $\theta^A$  there exists a large enough  $\Theta^A$  such that the value of insurance to the  $AA$  households is smaller than for the  $AN$  households. As a consequence, if there is “sufficient” ambiguity,  $AA$  households will have a lower value for insurance than  $AN$  households.

Second, I show that if insurance is valuable given pre-insurance beliefs then  $V^A < V^N$  implies CDC.<sup>18</sup> Formally I assume:

**Assumption 1** (Insurance is Valuable Given Pre-Insurance Beliefs).

$$\sum_{r \in R} p(r)u(\theta^A(r) + \gamma(r)) > \sum_{r \in R} p(r)u(\theta^A(r)),$$

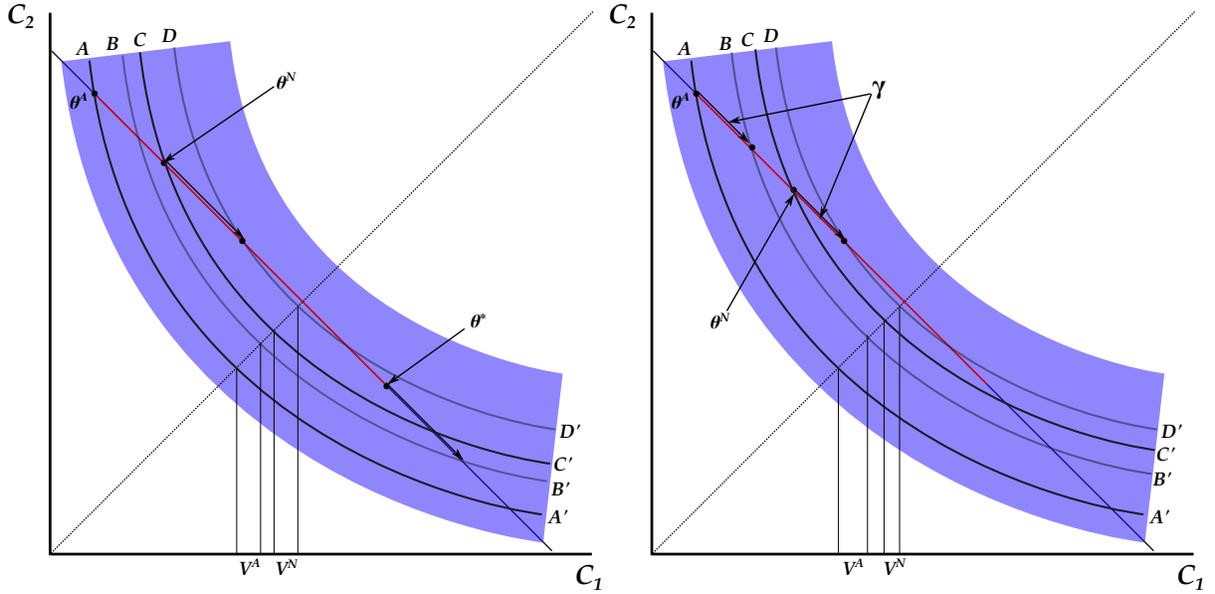
where  $\gamma$  is the insurance contract offered in the data.

As shown in the right panel of Figure 2.3, this assumption coupled with the assumption that  $\theta^N \in \Theta^A$  implies that  $\theta^A$  lies to the north-west of  $\theta^N$  when insurance moves money from state  $r_h$  to  $r_l$ . Given this, if households display decreasing absolute risk aversion (DARA) the value

<sup>17</sup>See Foster and Rosenzweig (1995) for evidence that learning is faster from own experience than from peers.

<sup>18</sup>I discuss the empirical relevance of this assumption below.

Figure 2.3: A Lower Value of Insurance for AA Households Implies CDC



of insurance when beliefs are  $\theta^A$  is greater than when beliefs are  $\theta^N$ .<sup>19</sup> Therefore, if  $V^A < V^N$  it must be because the set  $\Theta^A$  is large and, as depicted in the left panel of Figure 2.3, the belief of the AA households changes in response to the insurance. This change in beliefs implies CDC.

Third, I consider the impact of risk aversion. It is definitional of risk aversion that more risk averse households benefit more from actuarially fair insurance.<sup>20</sup> Therefore, if the rainfall insurance considered is of value to AN households, the benefit of the insurance will be increasing in risk aversion. Consider AA households on the other hand. The argument above establishes that for  $V^A < V^N$  to hold it must be the case that the minimizing belief with insurance ( $\theta^*$  in the left panel of Figure 2.3) lies to the right of the certainty line. As a consequence the insurance contract is seen as risk increasing relative to certainty. This implies that for the AA households the cost of the insurance is increasing in risk aversion. Therefore, the benefit for the AN households ( $V^N$ ) is increasing in risk aversion, while the cost ( $-V^A$ ) is increasing for AA households implying that  $V^N - V^A$  must be increasing in risk aversion.<sup>21</sup> Further intuition for this result can

<sup>19</sup>This comparative static is derived under the assumption that  $\theta^A$  is more risky than  $\theta^N$  in the sense that it is a mean preserving monotone spread (MPMS) and that insurance is also a MPMS. This is true in the example. Details for the more general case are given in Appendix C.

<sup>20</sup>In the partial insurance problem this requires that the insurance be MPMS.

<sup>21</sup>Details are given in Appendix C.

be gained by considering the case when all households are risk neutral. Risk neutrality implies that the insurance has no impact for either  $AA$  or  $AN$  households. Therefore, if it is observed that  $V^A < V^N$  for some households, these households must be risk averse.

Fourth, I argue that experience decreases the difference between  $AA$  and  $AN$  households. Intuitively the size of the set  $\Theta^A$  will decrease as information about the production function is revealed. If  $\Theta^A \rightarrow \theta^N$  as the amount of information increases, then behavior of the two types of households will converge.<sup>22</sup> The data includes measures of experience with the new crops and assuming that households only learn from their own experience then experience is a proxy for information. Therefore, if  $V^A < V^N$  at low levels of experience, and  $V^A = V^N$  at high levels of experience, it must be the case that  $V^N - V^A$  is decreasing in experience if the data set includes households with sufficient experience. This is the basic comparative static that is tested in the empirical section.

The question of whether experience leads to a monotonic reduction in  $V^N - V^A$  is a more difficult question that requires specification of a particular learning process. One plausible learning process implies that households rule out production functions that are sufficiently “far” from a particular observation. To formalize this notion denote  $\Theta_t$  to be the set of plausible production functions after  $t$  periods of experience,  $r_t$  the rainfall state in period  $t$  and  $x_t$  output in period  $t$ . Assume that households update according to the rule

$$\Theta_{t+1} = \left\{ \theta \in \Theta_t \mid \theta(r_t) - x_t \leq \kappa \frac{M_t(r_t)}{2} \right\} \quad (2.4)$$

where  $\kappa < 1$  and  $M_t(r) = [\max_{\theta \in \Theta_t} \theta(r_t) - \min_{\theta \in \Theta_t} \theta(r_t)]$ .

An ambiguity averse household choosing in period  $t$  considers all priors  $\Theta_t$  to be plausible, while an ambiguity neutral household uses one prior from within  $\Theta_t$ . In general, the learning process in (2.4) converges, so that  $V^N - V^A$  is eventually zero. It does not, however, produce a general result that learning leads to a monotonic reduction in  $V^N - V^A$ .<sup>23</sup> One special case is, however, of particular interest and does lead to a degree of monotonicity. Specifically, suppose that  $\Theta^A$  is symmetric around certainty and that  $\theta^N$  is not subject to learning, represents the truth and is such that insurance is valuable. In this setting learning by the ambiguity averse household will rule out first those priors for which insurance is not valuable with the implication that  $V^N - V^A$  is reduced. Once  $\Theta^A$  is symmetric around  $\theta^N$ , however, this monotonicity no longer

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<sup>22</sup>If priors are not degenerate, all  $\mu \in \mathcal{C}$  place positive probability on the truth for both  $AN$  and  $AA$  households and households learn by updating all priors according to Baye’s rule, then [Marinacci \(2002\)](#) implies that the behavior of  $AA$  and  $AN$  households will converge.

<sup>23</sup>See, Appendix C for further discussion.

holds.

I collect the four observations of this section as Proposition 2:

**Proposition 2** (Empirical Implications of VEA preferences). *If  $\theta^N \in \Theta^A$  then*

1. *For any  $\theta^N$  there exists  $\Theta^A$  such that  $V^N - V^A > 0$ .*
2. *If insurance is valuable given pre-insurance beliefs and  $u$  exhibits DARA then  $V^N - V^A > 0$  implies CDC.*
3. *If insurance is valuable given pre-insurance beliefs,  $u$  exhibits DARA and  $V^N - V^A > 0$  then  $V^N - V^A$  is increasing in risk aversion.*
4. *If  $V^N - V^A < 0$  and learning is faster from own experience then  $V^N(CI) - V^A(CI)$  is decreasing in experience.*

I conclude this section by discussing the empirical relevance of Assumption 1. Assumption 1 is a joint assumption regarding the insurance offered in the experiment of [Giné and Yang \(2009\)](#) and the beliefs of AA households. It essentially implies that in the environment under study caution without insurance would lead a household to favor beliefs in which the modern crop would be sensitive to drought. Two facts suggest that this is a plausible assumption. First, when asked the majority of households in the sample cited drought risk as the most important risk to their income. Second, a great deal of research has gone into producing new varieties of seeds for this area. Most of this work goes into producing drought resistant varieties. Both of these observations suggest that drought is among the main concerns and therefore that a significant concern about the modern crop would be that it is not drought resistant. I discuss the impact of relaxing this assumption in Section 2.7.

## 2.4.2 Application to Limited Liability Credit

In this section I show that with the exception of the risk aversion results, the same empirical predictions apply to a model with limited liability credit rather than rainfall insurance. For risk aversion, the implication for limited liability is the opposite of that for index insurance. The model is identical apart from the definition of the states and the definition of insurance. Assume there are two states of the world  $S = \{1, 2\}$ , the probability of each state is known and equal to  $p(1)$  and  $p(2)$ . With this exception, the basic setup is as above. A production function  $\theta$  is a mapping from  $S$  to  $\mathbb{R}$  and  $\theta^N \in \Theta^A$ . In this setting, I model a limited liability constraint as a minimum consumption level  $c^*$  in each state of the world.

Figure 2.4: The Impact of Limited Liability on Takeup

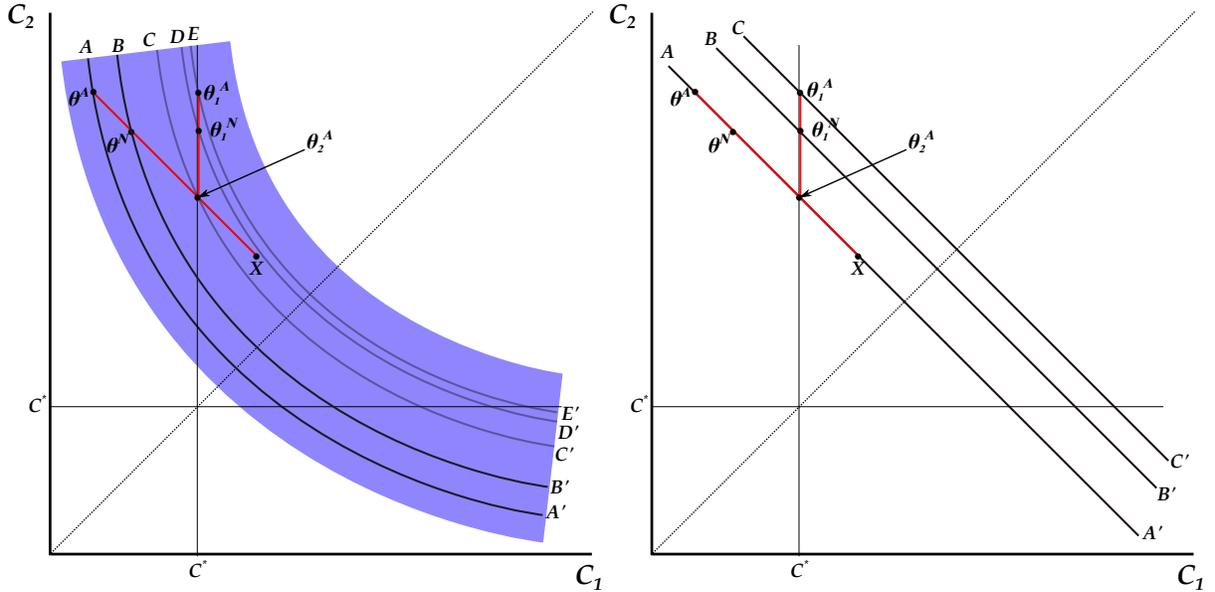


Figure 2.4 illustrates the main empirical implications. I first demonstrate that  $V^A < V^N$  implies CDC. Consider first the ambiguity neutral households. In the left panel of the figure,  $\theta^N$  is the belief of the AN households and the limited liability clause moves this consumption bundle to  $\theta_1^N$ . The value of the clause is measured by the difference between indifference curves  $DD'$  and  $BB'$ . Next consider the ambiguity averse households. The red line  $\theta^A X$  is the set  $\Theta^A$ , while the kinked red line  $\theta_1^A \theta_2^A X$  is the set of possible consumption bundles with limited liability. Each consumption bundle corresponds to a belief  $\theta \in \Theta^A$ . Once again, denote  $\theta^A$  the minimizing prior in the set  $\Theta^A$  when there is no limited liability. For a household with constant belief  $\theta^A$ , the value of limited liability is given by the difference between indifference curves  $AA'$  and  $EE'$  which is clearly larger than the benefit to a household with beliefs  $\theta^N$ . If beliefs change, however, AA households may benefit less from the limited liability. In particular, the minimizing prior with limited liability lies at the point  $\theta_2^A$  and the kink in the set  $\theta_1^A \theta_2^A X$  provides a positive explanation for AA households not valuing limited liability. In response to the consumption constraint, AA households concentrate their beliefs on a less risky production function, thus reducing the benefit of the limited liability constraint. As a consequence, if it is observed that  $V^A < V^N$  and assuming  $\theta^N \in \Theta^A$  it is possible to infer that there has been a change in beliefs, implying CDC.

The right hand panel of Figure 2.4 shows that risk aversion is not necessary for this argument. In that diagram all households are risk neutral and the limited liability constraint is beneficial to the *AN* households but not the *AA* households. The diagram also shows that for *AA* households limited liability acts as insurance, moving the production point closer to the certainty line. As is the case with index insurance, the benefit of this insurance is increasing in risk aversion. For *AN* households, however, limited liability acts as a state contingent transfer. The benefit of this transfer is measured by the first derivative of the utility function and is not necessarily related to risk aversion. Therefore  $V^A$  is increasing in risk aversion while  $V^N$  is constant in risk aversion, implying that  $V^N - V^A$  is decreasing in risk aversion. Finally, the same argument made above with respect to learning applies to the limited liability case. Limited liability therefore leads to the same empirical implications as in Proposition 2 with the exception that risk aversion is hypothesized to have the opposite effect.

### 2.4.3 Measuring Ambiguity and Risk Aversion

Testing the model requires measures of both risk aversion and ambiguity aversion. In this section I discuss the measures available in the two data sets. Ambiguity aversion is measured by the following question:

**Question 1** (Measuring Ambiguity). *You are going to play a game where you draw a ball out of a bag without looking. If the ball you choose is the “right” color, then you win 50 shillings. You get to decide which bag to choose the ball from.*

**Bag One:** *In Bag One there are 4 RED balls and 6 YELLOW balls. You must pick a RED ball in order to win.*

**Bag Two:** *In Bag Two there are 10 balls – some are RED and some are YELLOW. You decide what color ball wins. You must then pick this color ball to win.*

*Which bag would you like to choose from?*<sup>24</sup>

Decision makers were also given a visual aid, which is shown in Appendix A. The question was not incentivized. Those who chose bag one are treated as being *AA* and those who chose bag two are identified as *AN*. Because the probability of winning from the risky bag is only

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<sup>24</sup>This question was asked in Kenya, where the payout was in Kenyan Shillings. In Malawi the ratio of balls differed (5 in each bag 2 red and 3 yellow) and the value of the prize was left unspecified.

0.4, the question identifies those who show a *strict* preference for the risky urn in the Ellsberg two urn example. This is important as simply preferring the risky bag when the probability of winning is 0.5 is consistent with indifference between the two bags and therefore consistent with SEU. In terms of the representation (1.1) and Example 1, individuals identified as *AA* have  $\Pi \supseteq [0.4, 0.6]$  where an element  $\pi \in \Pi$  is the subjective probability that a red ball will be drawn. This implies that while those who chose bag 1 are labelled as *AN*, some portion of them may in fact be ambiguity averse.

For this measure of ambiguity aversion to have implications in a real world setting, there must be a link between the response to Question 1 and behavior in general. With VEA preferences, the degree of ambiguity aversion and the amount of perceived ambiguity are jointly measured by the “size” of the set  $\Pi$ . I do not have access to a measure of how ambiguous each agent perceives the crop decision, nor the urn choice problem in Question 1. Indeed it seems difficult to measure perception of ambiguity in an applied setting.<sup>25</sup> I, therefore, assume that when faced with a choice and endowed with the same information about that choice, all agents perceive the choice as equally ambiguous. Differences in the set  $\Pi$  can, therefore, be ascribed to ambiguity attitude. More formally, let a choice problem be a complete description of all possible acts, states of the world and available information. I assume the following regarding the size of the sets  $\Pi$ :

**Assumption 2** (Ambiguity Aversion is a Fixed Characteristic). *Let  $\mathcal{P}$  be the set of all choice problems. Define  $\Pi_i(l)$  as the set of priors for household  $i$  in choice problem  $l$ . Then*

$$\Pi_i(a) \subset \Pi_j(a) \Rightarrow \Pi_i(b) \subseteq \Pi_j(b) \quad (2.5)$$

*for all choice problems  $a, b \in \mathcal{P}$ . If (2.5) holds  $j$  is identified as more ambiguity averse than agent  $i$ .*

Assumption 2 coupled with the assumption that all agents have VEA preferences implies that those who are identified as *AA* by Question 1 will be weakly more ambiguity averse in real world choice problems, including the insurance choice problem motivating this paper. It should be noted that this assumption allows for learning. Specifically, all choice problems in  $\mathcal{P}$  should be assumed to contain a complete description of the information held by the household. Assumption 2 therefore only applies when households have the same amount of information and implies that the comparative statics with respect to ambiguity aversion are only valid controlling for experience. Question 1 remains a valid measure of ambiguity aversion so long as all

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<sup>25</sup>Several papers propose models that allow for a separation of ambiguity attitude and ambiguity perception. See for example [Klibanoff et al. \(2005\)](#) & [Ghirardato et al. \(2004\)](#) as well as the discussion in [Epstein \(2010\)](#).

households have the same information about the composition of the ambiguous urn.

Risk aversion is also a key measure. Both surveys include a measure of risk aversion based on that of [Binswanger \(1980\)](#). The respondent was asked to choose between several 50/50 gambles with the rewards chosen to reveal a higher coefficient of relative risk aversion if the households has CRRA preferences.<sup>26</sup> Again the questions were not incentivized and as this is a standard question I do not discuss it in detail, although it is worth noting that an assumption similar to Assumption 2.5 is required in all applied uses of this measure. The exact question can be found in Appendix B.

## 2.5 Policy Implications of the Model

In this section I briefly discuss policy implications of the model. While a static model is appropriate for analyzing a once off offer of insurance, as occurred in both experiments, a real world insurance product would be offered on an ongoing basis and requires a dynamic model. Unfortunately, the dynamic extension of ambiguity averse preferences is the subject of a large and unsettled literature (see, for example, [Gilboa and Schmeidler 1993](#), [Epstein and Schneider 2003](#), [Hanany and Klibanoff 2007](#) & [Siniscalchi 2006](#)). In the current setting there are two issues that arise when considering dynamic choice. First, the major emphasis of the literature on dynamic ambiguity averse preference is the possibility that AA preferences are dynamically inconsistent. In the setting of this paper, requiring dynamic consistency would allow a household to effectively hedge their choices over time, choosing a sequence  $\{insure, don't insure, \dots\}$ .

Second, households deciding on technology adoption in a situation of uncertainty face a tradeoff between current payoffs and learning. This tradeoff is usually captured by the multi-armed bandit model (see [Bergemann and Valimaki 2008](#) for a review). While I am unaware of any literature on ambiguity aversion and bandit problems, intuition suggests that the ongoing opportunity to purchase insurance may have different impacts on AA and AN agents in a bandit model. Incorporating strategic learning into the model may therefore have implications for policy analysis. Appendix D discusses these issues in more detail and proposes plausible assumptions under which the static model is appropriate for analyzing the behavior of AA households in response to insurance. Essentially, the static model is correct if households make decisions consistent with backward induction and are not strategic with respect to learning. The remainder of this discussion assumes that the implication of the static model will hold in a richer dynamic setting.

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<sup>26</sup>The questions also reveal an increasing coefficient of absolute risk aversion if preference are CARA, although the increments measured are not as uniform.

The (static) model has several important policy implications. The discussion of learning implies that index insurance is more likely to find success when the production function is well known and not open to ambiguity. A corollary is that index insurance is unlikely to be successful in promoting the use of new technologies. A policy that combines subsidies for short term use of a crop with long term insurance may overcome this difficulty by encouraging *AA* households to gain experience with the new crop.

The model also casts some doubt on the ability of index insurance to be useful even when the production technology is old. Several recent papers ([Bewley 1988](#), [Epstein and Schneider 2007](#) & [Al-Najjar 2009](#)) study formal learning models and show that under plausible assumptions ambiguity can persist in the long run. If these results apply, then index insurance will continue to suffer from low demand even if the production technology has been available for some time.

Third, while Proposition 1 shows that *AA* agents may not respond to any kind of index insurance, there is a potential role for marketing. There are two reasons for this belief. First, it can be argued from a theoretical perspective that being subject to the Ellsberg paradox is a mistake.<sup>27</sup> To see the mistake consider the Ellsberg paradox from Example 1 and suppose that a ball is drawn from each urn prior to the agents choice. In this context, flipping a coin to determine which color to choose renders bets on the ambiguous and risky urns indistinguishable. This raises the possibility that clever marketing could convince households of their mistake. Second, recent lab experimental work has shown that the effect of ambiguity aversion can be overcome by simple treatments that alter the status-quo. For example, [Roca et al. \(2006\)](#) document ambiguity seeking behavior in the Ellsberg two urn example when student subjects were “endowed” with the ambiguous urn and asked if they would like to trade for the risky urn. In the context of insurance contracts, this treatment suggests associating the new crop with the insurance from the outset. There may be other simple treatments that would have a similar effect.

Finally, the discussion of dynamic decision making under ambiguity in Appendix D suggests that *AA* households that are strategic with respect to learning will benefit more from insurance when they are certain that it will be provided on an ongoing basis. Thus insurance contracts should, as far as possible, be provided by trusted and permanent members of the community. From a project evaluation perspective these observations also highlight the importance of studies that assess ongoing, rather than temporary, insurance products.

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<sup>27</sup>See for example [Rustichini \(2005\)](#).

## 2.6 Tests of the Model

### 2.6.1 Empirical Specification and Test

In this section I present empirical tests of the model. To recap, the empirical strategy is to show that ambiguity averse households have a lower value of insurance ( $V^A < V^N$ ), a fact that is consistent with a high degree of ambiguity aversion and implies *CDC*. If this is found, the model implies that  $V^N - V^A$  is increasing in risk aversion in Malawi, decreasing in risk aversion in Kenya and decreasing in experience. This leads to three hypotheses:

1.  $V^A < V^N$  (Ambiguity averse households have a lower value of insurance);
2.  $V^N - V^A$  is decreasing in risk *tolerance* in Malawi and decreasing in risk *aversion* in Kenya; and
3.  $V^N - V^A$  is decreases in experience with the new crop.

To document these three facts I estimate:

$$\begin{aligned} Takeup_i = \beta^0 + \beta^1 AA_i + \beta^2 RT_i + \beta^3 Treat_i + \beta^4 AA_i \cdot Treat_i + \\ \beta^5 AA_i \cdot RT_i + \beta^6 RT_i \cdot Treat_i + \beta^7 AA_i \cdot RT_i \cdot Treat_i + \beta^8 Exp_i + \\ \beta^9 Exp_i \cdot Treat_i + \beta^{10} AA_i \cdot Exp_i + \beta^{11} AA_i \cdot Exp_i \cdot Treat_i + X_i' \beta^{12} + \eta_i, \end{aligned} \quad (2.6)$$

in Malawi and

$$\begin{aligned} Takeup_i = \beta^0 + \beta^1 AA_i + \beta^2 RA_i + \beta^3 Treat_i + \beta^4 AA_i \cdot Treat_i + \\ \beta^5 AA_i \cdot RA_i + \beta^6 RA_i \cdot Treat_i + \beta^7 AA_i \cdot RA_i \cdot Treat_i + \beta^8 Exp_i + \\ \beta^9 Exp_i \cdot Treat_i + \beta^{10} AA_i \cdot Exp_i + \beta^{11} AA_i \cdot Exp_i \cdot Treat_i + X_i' \beta^{12} + \eta_i, \end{aligned} \quad (2.7)$$

in Kenya. In these regressions:

1.  $Takeup_i$  is an indicator taking on value 1 if household  $i$  adopted the modern crop;
2.  $AA_i$  is an indicator variable taking on value 1 if household  $i$  was measured to be ambiguity averse;
3.  $Exp_i$  is a measure of how many years experience household  $i$  has with the modern crop;
4.  $RT_i$  is a measure of how risk tolerant household  $i$  is.
5.  $RA_i$  is a measure of how risk averse household  $i$  is.

6.  $Treat_i$  is an indicator taking on value 1 if household  $i$  was in the treatment group that was offered insurance (credit) and zero otherwise;
7.  $X_i$  is a vector of control variables; and
8.  $\eta_i$  is a mean zero error term.

The different specifications for the two data sets corresponds to the different expectations for the effect of risk aversion.<sup>28</sup>

I first discuss the interpretation for the Malawi data. Specification (2.6) allows me to test each of the three hypotheses while controlling for the other two. The tests are particularly simple because, as discussed above,  $V^A$  and  $V^N$  are simply measures of the impact of insurance on the probability of adopting the new crop.

First, specification (2.6) allows me to test whether  $V^A < V^N$  among those who are risk averse and inexperienced. The coefficient on  $Treat_i$  (i.e.  $\beta^3$ ) measures the impact of insurance on households that are measured to be ambiguity neutral and who are the least experienced and most risk averse. The impact of insurance on similar households but are measured to be ambiguity averse is the sum of the coefficients on  $Treat_i$  and  $AA_i \cdot Treat_i$  (i.e.  $\beta_3 + \beta_4$ ). Consequently testing whether  $V^A < V^N$  implies testing whether the coefficient on  $AA_i \cdot Treat_i$  is less than zero (i.e.  $\beta_4 < 0$ ).

Second, (2.6) allows for a test of whether  $V^N - V^A$  is decreasing in risk tolerance. The coefficient on  $RT_i \cdot Treat_i$  (i.e.  $\beta^6$ ), measures how the effect of the treatment on  $AN$  households changes as risk tolerance increases. The sum of the coefficients on  $AA_i \cdot RT_i \cdot Treat_i$  and  $RT_i \cdot Treat_i$  (i.e.  $\beta^6 + \beta^7$ ) measures the effect for  $AA$  households. Consequently, testing the claim that  $V^N - V^A$  is decreasing in risk tolerance requires testing whether the coefficient on  $AA_i \cdot RT_i \cdot Treat_i$  is positive (i.e.  $\beta^7 > 0$ ). Importantly, this test controls for the impact of experience and consequently tests whether risk aversion has the predicted impact *independent* of the effect of experience.

Third, specification (2.6) allows me to test whether  $V^N - V^A$  is decreasing in experience. The same logic as above implies that testing this hypothesis requires testing whether the coefficient on  $AA_i \cdot Exp_i \cdot Treat_i$  is positive (i.e.  $\beta^{11} > 0$ ).

Similar arguments apply to specification (2.7) when assessing the impact of limited liability credit. Hypothesis 1 implies  $\beta^4 < 0$  and Hypothesis 3 implies  $\beta^{11} > 0$ . Finally, if  $V^N - V^A$  is decreasing in risk aversion we expect to see  $\beta^7 > 0$ .

Before turning to the results of these tests one might wonder whether it is appropriate to test the combination of Hypotheses 2 and 3. That is, that the reduction in  $V^N - V^A$  caused

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<sup>28</sup>The difference is merely expositional, the two specifications are equivalent. If I estimate (2.6) in Kenya, testing Hypotheses 1 and 2 requires adding coefficients and performing  $F$ -tests.

by a decrease in risk aversion decreases in experience. In addition to being a mouthful, the theory does not necessarily support this hypothesis. Specifically, the theory does not imply that increasing risk aversion will monotonically decrease the effect of experience on  $V^N - V^A$ . For example, amongst very risk averse households, experience may have no impact as no *AA* households are adopting. As a consequence, while it is true that if the data contained people who were risk neutral we would expect experience to have no effect, it is not the case that we expect the effect of experience to decrease with risk tolerance. Therefore, while it is necessary to control for Hypothesis 2 while testing 3 (and vice-versa) as is done in (2.6), it is not appropriate to test their conjunction.<sup>29</sup>

## 2.6.2 Results

Table 2.3 shows the main results. Columns 1 - 3 show the results of regression (2.6) for the Malawi data. The columns differ in how risk tolerance is treated. Column 1 uses the raw risk tolerance categories based on Question 2. The interpretation of the marginal effect is difficult with this measure. In Column 2, I convert the raw measures to percentiles. In this column coefficients on *RT* measure the impact of a 10 percentile increase in how risk tolerant the household is. Column 3 uses a discrete measure of risk tolerance. Households with above median risk tolerance are coded as 1 and those with below median risk tolerance are coded as 0. All three columns include controls for household characteristics, a dummy for the region and a control for the distance to the rainfall gauge.<sup>30</sup>

All three columns support the three hypotheses. Consider first Hypothesis 1 (that ambiguity averse households benefit less from insurance). The coefficient on *AA.Treat* is always negative and strongly significant. Comparing the coefficient on *Treat* and *AA.Treat* in Columns 1 and 2 implies that among risk averse and inexperienced *AN* households, insurance increase takeup by about 15%. In contrast *AA* households decrease takeup by around 30% to 40% when offered insurance. These are large numbers given that the mean takeup among *AN* households in the

<sup>29</sup>I have tested the conjunction and find that a decrease in risk aversion significantly decreases  $V^N - V^A$  when experience is less than the mean and does not significantly affect  $V^N - V^A$  when experience is greater than the mean. The difference between the two estimates is, however, not significant.

<sup>30</sup>I discuss distance to the rainfall gauge and its important in more detail below. The controls decrease the standard errors as expected, but do not significantly alter the coefficients of interest and are not required for the important results to be statistically significant at conventional levels. The regressions also include a control for growth of groundnut in the past period and its interaction with ambiguity aversion and risk aversion. This is to control for the possibility that  $\alpha$  is correlated with *AA* because ambiguity averse households become “stuck” using old crop technologies. This effect should only be apparent for those who are ambiguity averse and risk averse. Leaving out this control does not affect the size or significance of the coefficients of interest. Further, the treatment effects are identified even if this control is correlated with the error.

Table 2.3: The Impact of Ambiguity Aversion on Adoption. Dep Var Takeup. OLS

	<i>Malawi</i>			<i>Kenya</i>		
	1	2	3	4	5	6
<i>Risk Measure</i>	<i>Raw</i>	<i>Percentile</i>	<i>Discrete</i>	<i>Raw</i>	<i>Percentile</i>	<i>Discrete</i>
<i>AA</i>	0.073 (0.110)	0.080 (0.130)	-0.003 (0.067)	0.103 (0.141)	0.108 (0.182)	0.151 (0.132)
<i>RT</i> ( <i>RA Kenya</i> )	0.031* (0.018)	0.019 (0.014)	0.067 (0.082)	0.011 (0.010)	0.013 (0.013)	0.128 (0.088)
<i>Treat</i>	0.114 (0.148)	0.175 (0.164)	0.004 (0.133)	0.458*** (0.147)	0.511** (0.180)	0.429*** (0.151)
<b><i>AA.Treat</i></b>	<b>-0.417***</b> <b>(0.124)</b>	<b>-0.482***</b> <b>(0.150)</b>	<b>-0.240***</b> <b>(0.080)</b>	<b>-0.552**</b> <b>(0.203)</b>	<b>-0.643**</b> <b>(0.250)</b>	<b>-0.520**</b> <b>(0.200)</b>
<i>AA.RT</i> ( <i>AA.RA Kenya</i> )	-0.027 (0.027)	-0.017 (0.020)	-0.062 (0.117)	-0.009 (0.020)	-0.008 (0.025)	-0.182 (0.178)
<i>RT.Treat</i> ( <i>RA.Treat Kenya</i> )	-0.047** (0.020)	-0.038** (0.016)	-0.246** (0.109)	-0.022 (0.017)	-0.028 (0.024)	-0.158 (0.160)
<b><i>AA.RT.Treat</i></b> ( <i>AA.RA.Treat Kenya</i> )	<b>0.070**</b> <b>(0.027)</b>	<b>0.050**</b> <b>(0.020)</b>	<b>0.281**</b> <b>(0.136)</b>	<b>0.042*</b> <b>(0.022)</b>	<b>0.051</b> <b>(0.030)</b>	<b>0.382*</b> <b>(0.218)</b>
<i>Exp</i>	-0.001 (0.004)	-0.001 (0.004)	-0.001 (0.004)	0.018 (0.017)	0.017 (0.017)	0.019 (0.017)
<i>Exp.Treat</i>	-0.003 (0.005)	-0.003 (0.005)	-0.003 (0.005)	-0.033 (0.022)	-0.032 (0.022)	-0.034 (0.022)
<i>AA.Exp</i>	-0.001 (0.003)	-0.001 (0.003)	-0.001 (0.004)	-0.025 (0.020)	-0.025 (0.020)	-0.026 (0.020)
<b><i>AA.Exp.Treat</i></b>	<b>0.010**</b> <b>(0.005)</b>	<b>0.010**</b> <b>(0.005)</b>	<b>0.010*</b> <b>(0.005)</b>	<b>0.056*</b> <b>(0.027)</b>	<b>0.056*</b> <b>(0.027)</b>	<b>0.057*</b> <b>(0.028)</b>
<i>Mean DV</i>	0.305	0.305	0.305	0.170	0.170	0.170
<i>Treat = 0 AA = 0</i>	(0.036)	(0.036)	(0.036)	(0.039)	(0.039)	(0.221)
<i>Observations</i>	730	730	730	409	409	409
<i>R-squared</i>	0.173	0.173	0.173	0.253	0.253	0.254

\*\*\*  $\Rightarrow p < 0.01$ , \*\*  $\Rightarrow p < 0.05$ , \*  $\Rightarrow p < 0.1$ . Standard errors clustered at the level of randomization. Controls Malawi: Region, age, female, female household head, years of schooling, house quality, land owned, income at baseline, saving account, committee member, distance to rainfall gauge and past year growth of groundnut. Controls Kenya: Region, age, female head, female respondent, years of schooling head, head literate, house quality, saving account, land owned, relation to chief, officer of SHG, time with SHG, household size and last year growth of export crop. Risk measure refers to how the risk tolerance measure is coded. Raw uses the raw data from Question 2 on a scale of 1 - 6, percentile converts these into percentiles of the population and the coefficient reported is for a 10 percentile change. Discrete divides the sample into two groups. Those with above median risk tolerance and those with below median risk tolerance.

control group group is roughly 30%.

Second, consider Hypothesis 2 (that the differential impact of insurance is decreasing in risk tolerance). Columns 1 - 3 all show a large and statistically significant decrease in  $V^N - V^A$  in response to an increase in risk tolerance. Column 2 is the easiest to interpret. It says that a 10 percentile increase in risk tolerance decreases  $V^N - V^A$  by about 5 percentage points. The same column estimates  $V^N - V^A$  to be 48% indicating that a move from the 0 percentile of risk tolerance to the 100th percentile completely removes the differential impact of ambiguity aversion. This is what would be expected from the theory. It is also interesting to note that Columns 1 - 3 all show the intuitive comparative static that among *AN* households, an increase in risk tolerance (decrease in risk aversion) leads to a decrease in the value of insurance. In contrast, when *AA* is not accounted for this data suggests that an increase in risk tolerance leads to higher insurance demand (see [Giné and Yang 2009](#)).

Third, the data supports Hypothesis 3 (that the differential impact of insurance is decreasing in experience). Columns 1 - 3 all show a large and statistically significant coefficient on the interaction *AA.Exp.Treat*, indicating that  $V^N - V^A$  is decreasing in experience. The results suggest that 1 year of additional experience with groundnut decreases the difference between *AA* and *AN* households by 1 percentage point. At the median level of risk aversion, Column 3 indicates that  $V^N - V^A$  is equal to approximately 25% suggesting that 20 years experience is required for the behavior of *AA* and *AN* households to converge, although this calculation may take the linearity assumption inherent in (2.6) too seriously.

Columns 4 - 6 present the results of regression (2.7) using the Kenya data. As with the Malawi results, the columns differ in how the risk aversion measure is treated. The regressions include controls for a similar set of demographic variables and dummy variables for region.

All three columns strongly support Hypothesis 1. Among the least experienced and most risk tolerant households, the credit treatment increased adoption by *AN* households by approximately 45% from a base of 17%. The increase for *AA* households was, however, significantly less as shown by the strongly negative coefficient on *AA.Treat*. In fact, the estimates imply that it is not possible to rule out that *AA* households do not gain from the credit.

Hypothesis 2 is also confirmed in the data, although the effect is not as strong as for the other hypotheses. The coefficient on *AA.RA.Treat* is positive in all three columns, and statistically significant in Columns 4 and 6, although only at the 10% level (*p*-values are 0.071, 0.104 and 0.094 for the three columns). Further, while the coefficient is always positive, the coefficients are only significant once controls are included.

Finally, Hypothesis 3 is also supported. All three columns show a positive coefficient on

*AA.Exp.Treat* although the coefficient is only significant at the 10% level ( $p \in [0.62, 0.7]$  for all three columns). The coefficient on *AA.Exp.Treat* in Column 6 indicates that it requires around 6-years of experience for the behavior of *AA* households to converge to that of *AN* households.

## 2.7 Alternative Explanations

In this section I discuss other models that could explain the results. Because the results are based on experimental data, the regressions above accurately identify the heterogeneous treatment effects. For example, the coefficient on the interaction *AA.Treat* is the impact of insurance on households that are measured to be ambiguity averse. Consequently, any confound must come from omitted variables that are correlated with *AA*, *RA* or *Exp*, but are not included in the regressions. Moreover, these omitted variables cannot simply be correlated with demand for the new crop. Because I interpret only coefficients on terms that are interacted with *Treat*, potential confounding variables must cause low demand for insurance. In terms of the model, the results are robust to correlations between *RA*, *AA* or *Exp* and  $\alpha$ . Alternative explanations for the main results must therefore imply that *AA* household A) do not care about risk, B) perceive the insurance to be risk increasing, C) have a land holding such that the insurance actually is risk increasing or D) do not trust the insurance to payout. I discuss each of these possibilities under their own headings below.

Further, the claim that ambiguity aversion can be ameliorated through experience with the new crop requires the impact of experience be causal. In my model the differences in experience would be driven by differences in  $\alpha$ . Other household characteristics, however, might cause households to become experienced and also be correlated with insurance demand. If this is the case then it is not possible to put a causal interpretation on the impact of experience. The main reason to believe that the effect is causal is that it is hard to think why an omitted variable that causes experience should have different impacts on the insurance demand for households measured to be *AA* and *AN*, as shown in Table 2.3. Nevertheless, the following sections consider the possibility that trust and risk tolerance are jointly correlated with measured ambiguity aversion and experience. The evidence tends to suggest that these potential confounds do not drive the results.

### 2.7.1 Households Measured to Be Ambiguity Averse Are Risk Tolerant

If measured ambiguity aversion is correlated with risk tolerance, this could drive the main implication that *AA* households demand less insurance. Several observations, however, suggest

this is not what drives the results. First, Table 2.3 shows that households measured to be *AA* increase demand for insurance as risk tolerance increases while the opposite is true of those measured to be ambiguity neutral. This result is difficult to explain with a model in which *AA* households are merely more risk tolerant. If it were the case that *AA* households merely decrease takeup at a lower rate as risk tolerance increases, this would be consistent with a non-linear impact of risk tolerance. Table 2.3, however, suggests that the value of insurance is decreasing in risk tolerance for *AN* households, but increasing for *AA* households, although the sum of the coefficients is not significantly different from zero at conventional levels. Second, an explanation based entirely on risk tolerance cannot easily explain the differential impact of experience on the value of insurance. Third, as discussed in Section 2.4.2 the simple model of limited liability insurance does not support the implication that the value of a limited liability clause should be decreasing in risk tolerance. Explaining the results from Kenya, therefore, requires more than just a correlation between measured *AA* and risk tolerance.

Finally, suppose that the modeling of ambiguity aversion based on VEA preferences is completely wrong and all the data can be explained by a correlation between measured *AA* and risk tolerance. Then, consider estimating

$$\begin{aligned}
Takeup_i = & \beta^0 + \beta^1 AA_i + \beta^2 Exp_i + \beta^3 Treat_i + \beta^4 AA_i \cdot Treat_i + \\
& \beta^5 AA_i \cdot Exp_i + \beta^6 Exp_i \cdot Treat_i + \beta^7 AA_i \cdot Exp_i \cdot Treat_i + \\
& \beta^8 RT_i + \beta^9 RT_i \cdot Treat_i + \beta^{10} RT_i \cdot Exp_i + \beta^{11} RT_i \cdot Exp_i \cdot Treat_i + \eta_i.
\end{aligned} \tag{2.8}$$

Suppose that *RT* is an imperfect measure of risk tolerance, but that it is correlated with a single dimensional behaviorally relevant measure of risk aversion. Under these assumptions, if risk tolerance is driving the results, estimating (2.8) with and without the controls for *RT* will lead to a change in the estimates of  $\beta^4$  and  $\beta^7$ . Table 2.4 shows the results of doing this for both data sets. Columns 1 and 2 show the results for Malawi and 3 and 4 for Kenya. In both cases the odd column shows the coefficients without risk tolerance controls and the even columns show the results with the controls. The table shows that the estimates do not change substantially, and if anything move in the opposite direction required for risk tolerance to explain the results.<sup>31</sup> The only way in which a correlation between risk tolerance and measured *AA* can explain all the results is if the measure of risk tolerance in the data is uncorrelated with true risk aversion.

<sup>31</sup>Note that the results in Table 2.4 differ from those in Table 2.3 as equation 2.8 does not allow for *RT* to have a differential impact on those who are *AA*. This is consistent with the counterfactual that there is in fact nothing different about *AA* households except for the correlation between measured *AA* and risk tolerance.

Table 2.4: The Impact of Ambiguity Aversion and Experience On Take-up – With and Without Risk Aversion Controls. Base Regression is the Same as Table 2.3 Without Interactions for Risk Aversion

	<i>Malawi</i>		<i>Kenya</i>	
	1 N	2 Y	3 N	4 Y
<i>Risk Control</i>				
<i>AA</i>	0.042 (0.053)	0.043 (0.051)	0.053 (0.061)	0.057 (0.059)
<i>Treat</i>	-0.061 (0.136)	-0.016 (0.177)	0.333*** (0.088)	0.360*** (0.086)
<i>Exp</i>	0.000 (0.004)	-0.011 (0.007)	0.034 (0.020)	0.034 (0.026)
<i>AA.Treat</i>	<b>-0.156**</b> <b>(0.071)</b>	<b>-0.158**</b> <b>(0.067)</b>	<b>-0.188**</b> <b>(0.086)</b>	<b>-0.193**</b> <b>(0.082)</b>
<i>AA.Exp</i>	-0.002 (0.003)	-0.001 (0.003)	-0.032 (0.021)	-0.034 (0.021)
<i>Exp.Treat</i>	-0.004 (0.006)	-0.004 (0.010)	-0.037 (0.024)	-0.042 (0.029)
<i>AA.Exp.Treat</i>	<b>0.010**</b> <b>(0.005)</b>	<b>0.010**</b> <b>(0.004)</b>	<b>0.051*</b> <b>(0.028)</b>	<b>0.053*</b> <b>(0.028)</b>
<i>Mean DV</i>	0.305	0.305	0.170	0.170
<i>Treat = 0 AA = 0</i>	(0.036)	(0.036)	(0.039)	(0.039)
<i>Observations</i>	731	731	409	409
<i>R-squared</i>	0.153	0.162	0.211	0.212

\*\*\*  $\Rightarrow p < 0.01$ , \*\*  $\Rightarrow p < 0.05$ , \*  $\Rightarrow p < 0.1$ . Standard errors clustered at the level of randomization. Controls Malawi: Region, age, female, female household head, years of schooling, house quality, land owned, income at baseline, saving account and committee member. Controls Kenya: Region, age, female head, head schooling, head literate, house quality, saving account, land owned, officer of SHG, time with SHG. Risk aversion control uses risk measure from 2 converted to a percentile.

### 2.7.2 Households Measured to be Ambiguity Averse Perceive Insurance to be Risk Increasing

To derive the implication that  $V^N - V^A > 0$  implies CDC, I use Assumption 1 – that insurance is valuable given pre-insurance beliefs. This assumption coupled with the assumption that  $\theta^N \in \Theta^A$  rules out the possibility that AA households simply perceive the new crop to be less risky. If either of these assumptions is not true, the results for Malawi are consistent with AA households having a constant belief that the new crop is not risky. There are, however, several reasons to believe that this is not the case. First, a constant belief cannot explain the Kenya results. A constant optimistic belief implies that AA households always believe the limited liability constraint will not bind. As a consequence limited liability does not act like insurance and there should be no differential impact of risk aversion. Second, in Malawi this explanation would require that households measured to be AA believe that the new crop is more drought resistant. Given the weather patterns in the area this is a particularly optimistic view of the crop. It seems unlikely that this optimistic view would be correlated with a question designed to measure some sort of pessimism. There is some evidence that this is not the case. Households in Malawi were asked whether they believe the new crop is more or less drought resistant than an older version of the crop. There is no statistically significant differences between their responses and if anything AA households were less likely to believe that the new crop is drought resistant. Third, in the context of limited liability credit, explaining the results would require that AA households believe that their income is less likely to fall below the limited liability constraint. Again, this belief seems unlikely to be correlated with a question designed to measure pessimism and there is again some evidence against the interpretation. Households in the Kenya survey were asked a series of questions regarding how optimistic they are. An index was created from these questions and as shown in Table 2.2 households measured to be AA self reported as being less optimistic.

### 2.7.3 Insurance is Risk Increasing for Households Measured to be Ambiguity Averse

Explaining the Malawi results in Table 2.3 requires both that AA households have less need of insurance *and* that the insurance is risk increasing for them. An alternative explanation for low demand for index insurance, which can deliver both these implications, is basis risk. The simple idea is that rainfall on a farmer's plot is not perfectly correlated with the rainfall measure. There may, therefore, be states in which the insurance does not pay out, but the rainfall on the actual plot was very low. It can be shown that even if the correlation between actual rainfall

and measured rainfall is quite high it is possible for risk averse farmers to believe that rainfall insurance is risk increasing. There are two reasons to believe that this is not driving the results. First, it seems unlikely that basis risk is correlated with whether a household was measured to be *AA*. Second, the Malawi data contains a measure of distance from the household to the rainfall gauge. So long as plot location is correlated with household location this measure will be correlated with basis risk. Table 2.1 shows that this measure is not correlated with measured *AA*, although *AA* households were more likely to know the location of the rainfall gauge. In order to verify that distance to the gauge does not drive the results I undertook a similar analysis to that in Section 2.7.1, estimating (2.6) with and without controls for distance to gauge (or the fact that it is missing) and its interaction with *Exp*, *Treat* and *RT*. The inclusion of the controls has almost no impact on the coefficients of interest implying that basis risk can only explain the results if measured distance to gauge is uncorrelated with true basis risk.<sup>32</sup>

#### 2.7.4 Households Measured to be Ambiguity Averse are Low Trust

It is possible that households that are not trusting avoided the ambiguous urn in Question 1 as they did not trust the experimenter not to alter the composition of the ambiguous urn. Indeed, Table 2.1 suggests that this may be the case – *AA* households are less trusting according to a series of generalized trust questions.

This correlation between *AA* and trust may drive the results. A low trust household may not trust the insurance company to pay out. Further, this possibility could also drive the risk tolerance and experience results. Concern about non-payment is likely increasing in risk aversion, and experience with the new crop may increase trust in sellers of the seeds and NGOs. There are, however, several reasons why trust is unlikely to explain the results. First, Question 1 was not incentivized. As such, it is more of a conceptual question and there is no need for the respondent to trust the experimenter. Second, it seems hard to explain the Kenya results as based on trust. The Kenyan experiment involves giving credit and there is no need for the household to trust the credit company in order to benefit from credit. The argument would have to be that an *AA* household does not trust the lender to respect the limited liability constraint. This seems like a stretch.

Third, the Malawi data set contains a large number of questions designed to measure trust. I

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<sup>32</sup>Related to this issue, it is possible that *AA* households simply have less risky plots. To test this hypothesis I constructed measures of “profitability” in the previous season in Malawi by calculating the value of crop yield divided by the value of land sown. I computed the variance of this measure within the *AA* and *AN* groups as well as discrete experience and risk tolerance groups. There is no evidence that this variance measure differs across the groups.

conduct a similar analysis to that in Table 2.4, presenting results both with and without controls for measured trust and its interactions. Table 2.5 shows the results. The first column reports the regression coefficients from Column 2 of Table 2.3 (I use the percentile measure of risk tolerance as it is easiest to interpret. The results are not sensitive to this choice). Columns 2 - 5 have controls for variables designed to measure trust in the rain gauge, the insurance company, the finance companies providing the seeds and general trust. The questions in Columns 2 - 4 are of the form “On a scale of 1 - 10 how much do you trust ... ” while the generalized trust questions are similar to those in the GSS and Glaeser et al. (2000).<sup>33</sup> Table 2.5 shows that the inclusion of the trust controls do not substantially change the coefficients of interest, consequently, for trust to explain the results, it would have to be the case that these 4 trust measures have almost no or negative correlation with the true value of a households trust.

While these arguments suggest that trust does not drive the results, it is also not clear the trust explanation is of concern. A model of trust that gives the experience and risk aversion results reported in Table 2.3 has very similar implications to the ambiguity aversion model presented in Section 2.3. The major difference would be the marketing methods that would increase insurance demand. For example, trust may be increased by changing the person selling the insurance contract, while ambiguity may be avoided by marketing aimed to alter the status-quo. Much more research is required to determine which, if any, of these suggestions are effective whether trust or ambiguity is the relevant behavioral notion.

## 2.8 Conclusions

I argue that ambiguity aversion implies low demand for index insurance. The theoretical argument is strongly supported using data from two experiments in Africa. The theory suggests that index insurance will be more effective in areas where the production technology is well known and will be ineffective in promoting take-up of new technologies. A policy of short term subsidization and long-term insurance may help to alleviate low demand for the insurance and encourage take-up at the same time.

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<sup>33</sup>There is some evidence that these questions do not capture trust well. See Glaeser et al. (2000).

Table 2.5: The Impact of Ambiguity Aversion On Take-up. Same as Table 2.3 With and Without Trust Controls

<i>Trust Control</i>	<i>Malawi</i>				
	1 <i>None</i>	2 <i>Rain Gauge</i>	3 <i>Insurance</i>	4 <i>Finance</i>	5 <i>General</i>
<i>AA</i>	0.080 (0.130)	0.083 (0.125)	0.069 (0.132)	0.123 (0.140)	0.067 (0.133)
<i>RT</i> ( <i>RA Kenya</i> )	0.019 (0.014)	0.016 (0.017)	0.017 (0.014)	0.016 (0.018)	0.013 (0.015)
<i>Treat</i>	0.175 (0.164)	0.100 (0.157)	0.197 (0.171)	0.434* (0.220)	0.134 (0.146)
<b><i>AA.Treat</i></b>	<b>-0.482*** (0.150)</b>	<b>-0.525*** (0.154)</b>	<b>-0.506*** (0.154)</b>	<b>-0.566*** (0.166)</b>	<b>-0.479*** (0.148)</b>
<i>AA.RT</i> ( <i>AA.RA Kenya</i> )	-0.017 (0.020)	-0.024 (0.019)	-0.015 (0.020)	-0.020 (0.022)	-0.017 (0.020)
<i>RT.Treat</i> ( <i>RA.Treat Kenya</i> )	-0.038** (0.016)	-0.027 (0.024)	-0.043** (0.017)	-0.042* (0.024)	-0.032** (0.015)
<b><i>AA.RT.Treat</i></b> ( <i>AA.RA.Treat Kenya</i> )	<b>0.050** (0.020)</b>	<b>0.056** (0.022)</b>	<b>0.055** (0.021)</b>	<b>0.055** (0.022)</b>	<b>0.051** (0.020)</b>
<i>Exp</i>	-0.001 (0.004)	0.000 (0.004)	-0.001 (0.004)	0.001 (0.005)	-0.001 (0.004)
<i>Exp.Treat</i>	-0.003 (0.005)	(0.002) (0.006)	(0.003) (0.005)	(0.008) (0.008)	(0.004) (0.006)
<i>AA.Exp</i>	-0.001 (0.003)	0.001 (0.004)	-0.001 (0.003)	-0.003 (0.004)	0.001 (0.004)
<b><i>AA.Exp.Treat</i></b>	<b>0.010** (0.005)</b>	<b>0.010* (0.006)</b>	<b>0.010* (0.005)</b>	<b>0.013** (0.006)</b>	<b>0.009* (0.005)</b>
<i>Mean DV</i>	0.305	0.305	0.305	0.305	0.305
<i>Treat = 0 AA = 0</i>	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)
<i>Observations</i>	730	730	730	730	730
<i>R-squared</i>	0.173	0.181	0.181	0.200	0.179

\*\*\*  $\Rightarrow p < 0.01$ , \*\*  $\Rightarrow p < 0.05$ , \*  $\Rightarrow p < 0.1$ . Standard errors clustered at the level of randomization. Controls Malawi: Region, age, female, female household head, years of schooling, house quality, land owned, income at baseline, saving account, committee member, distance to rainfall gauge and past year growth of groundnut. Controls Kenya: Region, age, female head, female respondent, years of schooling head, head literate, house quality, saving account, land owned, relation to chief, officer of SHG, time with SHG, household size and last year growth of export crop. Risk aversion control uses risk measure from 2 converted to a percentile. Trust measures are of the form "on a scale of 1-10 how much do you trust ...". General trust measure is an index from General Social Survey style questions.

## 3 Risk Sharing In the Presence of Ambiguity

### 3.1 Introduction

In this part of the paper I consider whether ambiguity aversion can explain the failure of complete risk sharing documented, for example, by [Townsend \(1994\)](#) and [Udry \(1994\)](#). I show theoretically that ambiguity aversion, operationalized through an assumption of VEA preferences, can explain partial but incomplete risk sharing. I then derive simple testable implications of the theory for a panel data set consisting of measures of consumption and income at a household level. I test the theory using two panel data sets from developing countries – the ICRISAT data and Townsend’s Thai monthly panel. I am unable to reject the model using either of these data sets and I conclude that ambiguity aversion is a sufficient explanation for incomplete risk sharing in these two diverse settings.

The intuition for the theory is given by Jones’s example in the introduction. The theory has two testable implications.<sup>1</sup> First, if the income process is symmetric in a sense made precise below, and all households are equally ambiguity averse, households that are giving (receiving) transfers in a given period will have the same effective beliefs about the state observed in that period. Common beliefs imply households that are giving (receiving) have the same allocation (controlling for Pareto weights). The same reasoning behind Townsend’s (1994) test then implies that consumption should not be correlated with income within the group of giving (receiving) households. Second, the different beliefs of giving and receiving households create a wedge between their consumption levels. Households whose income falls inside this wedge will choose not trade, consuming their own income. For this group of households consumption increases one-to-one with income. I simultaneously test these two implications by estimating a non-linear least squares model that estimates the “wedge” between giving and receiving households. I test that the coefficient on income is one within the wedge and zero elsewhere. I am unable to reject either of these hypotheses.

The results in this section can be seen as a simple generalization of Townsend’s (1994) test

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<sup>1</sup>The aim is to provide simple tests that are similar to those traditionally tested in the risk sharing literature. The theory may have testable implications other than those emphasized here, and may have implications that are testable in the absence of the strong symmetry assumption that I impose. I see this as a first approach that shows the plausibility of an ambiguity based explanation for incomplete risk sharing.

of perfect risk sharing. While Townsend assumes all households have the same preferences and beliefs, I relax the second assumption. All households have the same risk preferences and ambiguity preferences, but beliefs will differ at the optimum because of CDC.

Given the *vast*<sup>2</sup> literature on the full risk sharing hypothesis and the many plausible explanations already available for its failure, the reader may well question the need for another explanation. In my view there are two good reasons for being concerned about *exactly* why risk sharing is incomplete.

First, the model matters for policy and our understanding of the economy. A typical explanation for incomplete risk sharing invokes some kind of incentive problem, for example limited commitment, moral hazard or hidden income. In each of these cases the incentive to comply with a risk sharing contract is provided by the threat of expulsion from the contract in the future. The effectiveness of informal insurance is therefore dependent on the difference in utility under the future contract and autarky.<sup>3</sup> Policies which seek to provide financial access to households – for example insurance, credit or saving – will tend to increase the value of autarky, thus making enforcement more challenging for the informal arrangement. Formal access to finance, therefore, has the potential to crowd out informal insurance and the policy value of such interventions is ambiguous.<sup>4</sup>

In contrast, risk sharing in the presence of ambiguity aversion leads to an outcome that is Pareto optimal given the effective equilibrium beliefs of the households, and there need be no incentive problem to overcome. The finding of correlation between consumption and idiosyncratic income is therefore compatible with an absence of incentive problems.<sup>5</sup> As a consequence, policies that provide access to finance need not crowd out informal risk sharing. Further, while the empirical work in this paper does not allow for heterogeneity of ambiguity attitude, it is easy to show that an ambiguity neutral households that shares risk with an ambiguity averse household can benefit from an insurance policy that further mitigates idiosyncratic risk. Thus an ambiguity based explanation of risk sharing implies that formal access to insurance may be valuable, and need not have deleterious effects on informal arrangements.

Second, risk sharing contracts are a simple setting in which it is possible to formulate rigorous tests of theories of misallocation. This justifies the emphasis on *why* risk sharing is in-

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<sup>2</sup>See for example [Kinnan \(2010\)](#) for a brief discussion of the current literature

<sup>3</sup>See, for example, [Ligon et al. \(2002\)](#) in the context of limited commitment.

<sup>4</sup>See [Ligon et al. 2000](#) for a formal demonstration of this possibility in the context of the limited commitment model of risk sharing, [Arnott and Stiglitz 1991](#) for a related discussion the context of moral hazard and [Attanasio and Rios-Rull 2000](#) for some empirical evidence.

<sup>5</sup>Perfect risk sharing in the presence of heterogenous risk preferences, as studied by [Mazzocco and Saini \(2009\)](#) and [Schulhofer-Wohl \(2010\)](#), also has this implication.

complete. While studies that attempt to describe network based risk sharing (eg. [Fafchamps and Lund 2003](#)) may well describe what risk sharing looks like, they do not tell us why the remaining risk cannot be traded away and therefore do not give any policy direction on removing misallocation. While not a focus of this paper, an ambiguity based theory of misallocation has potentially different policy implications from the more traditional incentive based theories.

The remaining discussion of risk sharing is organized as follows. Section 3.3 introduces a formal model of risk sharing under ambiguity aversion and shows by way of example that VEA preferences can explain a positive correlation between consumption and income. Section 3.3 discusses the empirical implications of the model. The focus of that section is on formalizing the notion of symmetry that is required if the model is to have testable implications. Section 3.4 gives a short discussion of other relevant literature. Section 3.5 briefly describes the data and 3.6 presents the empirical results. Finally, Section 3.7 offers some conclusions. The results in this paper can best be thought of as the beginning of a research project. I conclude from my test that ambiguity aversion is a sufficient explanation for incomplete risk sharing. The model, however, has other implications that I have not tested. I outline the direction of future research in the conclusion.

## 3.2 Model

### 3.2.1 Setting

Consider a world with one consumption good and  $N$  households. There is only one time period and  $S$  states of nature, indexed by  $s$ .<sup>6</sup> Each household receives an endowment of the single consumption good, which depends on the state  $s$ . Denote the endowment of household  $i$  in state  $s$ ,  $y_s^i$ . All household are ambiguity averse and share a common (closed convex) set of priors  $\Pi$  where  $\pi \in \Pi$  is a prior  $\{\pi_1, \dots, \pi_S\}$  such that  $\pi_s \in (0, 1)$  for all  $s \in S$  and  $\sum_{s \in S} \pi(s) = 1$ .

Households assess state contingent consumption bundles  $c^i = \{c_s^i\}_{s \in S}$  according to the criterion

$$U(c^i) = \min_{\pi \in \Pi} \left( \sum_{s \in S} \pi_s \left( u(c_s^i) - u(y_s^i) \right) \right), \quad (3.1)$$

where  $u$  is a twice continuously differentiable, strictly concave utility function that is common to all households.

An optimal risk sharing contract in this setting is a state contingent consumption plan,  $c =$

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<sup>6</sup>The analysis is simple to extend to multiple time periods so long as the income process is stationary and households are allowed to have different probability assessments in each period.

$\{c^1, \dots, c^N\}$ , which specifies for each household  $i$  a consumption level  $c_s^i$  for each state of the world and is the solution to

$$\begin{aligned} \operatorname{argmax}_c \sum_{i=1}^N \mu_i U(c^i) \quad \text{subject to} \\ \sum_{i=1}^N c_s^i \leq \sum_{i=1}^N y_s^i \quad \forall s \in S. \end{aligned} \tag{3.2}$$

I return to the general solution to this problem in section 3.3, but begin by discussing a simple static two state example that illustrates the main characteristics.

### 3.2.2 An Edgeworth Box Economy

In this section I discuss the solution to problem (3.2) in an example with two households,  $A$  and  $B$ , two states of the world, 1 and 2, and no aggregate uncertainty. In this context the set of priors can be parameterized so that  $\Pi = \{p_1 + \alpha, p_2 - \alpha\}$  with  $\alpha \in [-\kappa, \kappa]$  and  $p_1 + p_2 = 1$ . The parameter  $\kappa$  determines the size of the set  $\Pi$  and is a measure of ambiguity.<sup>7</sup>

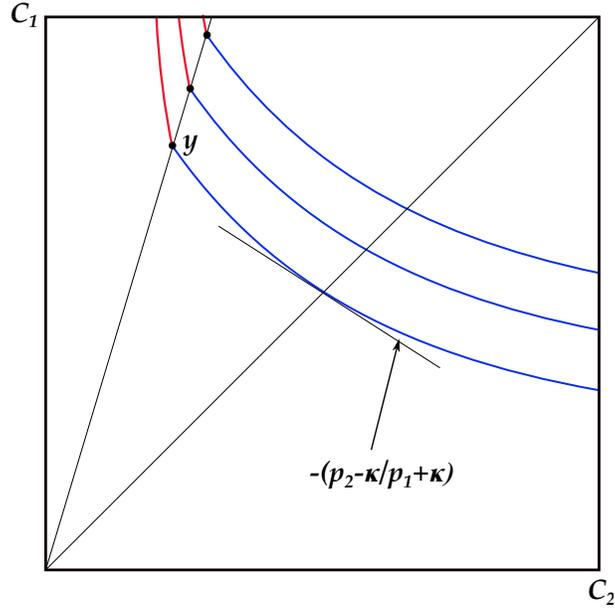
Figure 3.1 shows an example of a household's indifference curves when  $u = \ln$ . The point  $y$  is the endowment point and the indifference curves are "kinked" along a ray from the origin through the endowment point. "Below" the endowment point, the indifference curves have a slope  $-(p_2 - \kappa)u'(c_2)/(p_1 + \kappa)u'(c_1)$  and "above" the endowment point the indifference curve has slope  $-(p_2 + \kappa)u'(c_2)/(p_1 - \kappa)u'(c_1)$ . As a consequence, the kink becomes more extreme as  $\kappa$  increases.

In the absence of ambiguity ( $\kappa = 0$ ), if households have the same utility function, agree on probabilities, and there is no aggregate uncertainty, the optimal risk sharing contract lies on the certainty line. With ambiguity, however, this is no longer the case. Figure 3.2 illustrates this implication in an Edgeworth box. The certainty line lies below the endowment for household  $A$ , but above the endowment for household  $B$ . As a consequence, the indifference curves do not have the same slope at the certainty line. When considering an allocation on the certainty line, household  $A$  believes that state 1 is relatively more likely and state 2 is relatively less likely. Household  $B$ 's beliefs are the opposite and, as a consequence, household  $A$  is willing to make a transfer to household  $B$  in state 2 in return for a transfer in state 1. This moves the optimal

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<sup>7</sup> $\kappa$  can be thought of as a measure of both ambiguity and ambiguity aversion. I assume throughout that all households have the same degree of ambiguity aversion and perceive the same amount of ambiguity in any state. The distinction between the two concepts, therefore, has no relevance in this context. For a discussion of the issues involved see, for example, [Ghirardato et al. \(2004\)](#).

Figure 3.1: Indifference Curves for VEAP Preferences



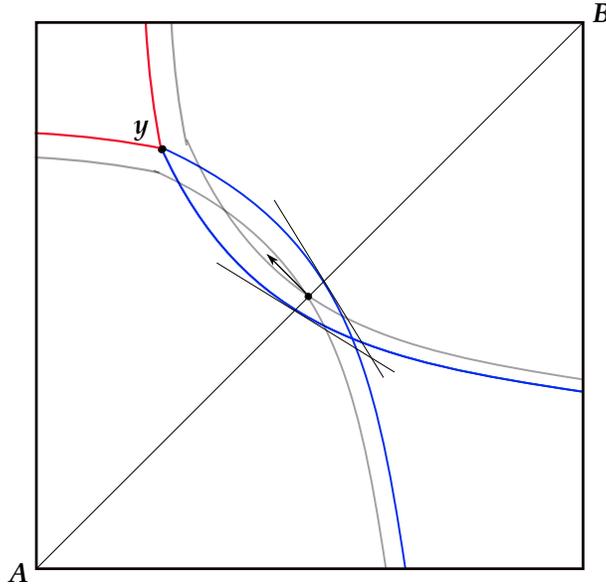
contract away from the certainty line toward the endowment. This effect enables ambiguity aversion with VEA preferences to explain partial, but incomplete insurance.

To give a concrete example, suppose  $u = \ln$ ,  $p_1 = p_2 = \frac{1}{2}$ ,  $\kappa = \frac{1}{4}$ ,  $y^1 = \{25, 5\}$  and  $y^2 = \{5, 25\}$ . The optimal risk sharing contract in this setting is

$$\begin{aligned} c^1 &= \left\{ \frac{45}{2}, \frac{15}{2} \right\} \\ c^2 &= \left\{ \frac{15}{2}, \frac{45}{2} \right\}. \end{aligned}$$

with  $\alpha = -\kappa$  for household  $A$  and  $\kappa$  for households  $B$ . In the example  $c_i = 3.75 + 0.75y_i$  showing that consumption is correlated with income even after controlling for a fixed effect for each household and a time effect (both of which are zero in this setting). Thus the model generates an explanation for the correlation between consumption and income that is found in many empirical studies. The correlation occurs because households that have high income believe that they will be giving it away. The model then implies that these households believe that this state is more likely and as a consequence households with higher income receive more of the aggregate endowment.

Figure 3.2: Perfect Risk Sharing is Not Optimal With VEAP



### 3.3 Testable Implications

In this section I derive testable implications of the theory. I first provide some intuition and then discuss the more general case including the symmetry assumption alluded to in the introduction.

#### 3.3.1 Intuition For a Test of The Theory

Having established that the model is capable of explaining the results of [Townsend \(1994\)](#), this section provides some intuition for a test of the theory. I continue with the Edgeworth Box example and use [Figure 3.3](#) to illustrate the argument.

Suppose that there are an even number of households  $\{1, \dots, N\}$  that can be paired  $(A, B)$  so that  $y_s^A + y_s^B = \text{constant}$  for all pairs and states. Further assume that expected income  $(\frac{1}{2}y_1^i + \frac{1}{2}y_2^i)$  is the same for all households as are the Pareto weights. In [Figure 3.3](#) these assumptions imply that all endowments lie on the line  $DD'$  with  $A$  households having  $y_1^A \geq y_2^A$  and  $B$  households having  $y_1^B \leq y_2^B$ .

Consider first a pair of households with endowment at  $y$ . An optimal contract between this pair (with equal Pareto weights) is found where their indifference curves are tangent. This is

some point  $c$ , below the endowment. Because the indifference curves are kinked at the endowment point, all pairs of households with an endowment between  $c$  and  $D$  also have tangent indifference curves at  $c$ . As a consequence, for those pairs with endowments above  $c$ , all  $B$  households will have the same consumption as will all  $A$  households. Next consider pairs of agents with endowments between  $c$  and  $D'$ . For these agents there is no feasible allocation which dominates the endowment and therefore these households will not trade.

This discussion suggests that there are three groups of households. Those with endowment below  $c$  consume their own endowment. For those agents with endowments above  $c$ ,  $A$  households consume relatively more in state 1 while  $B$  households consume relatively more in state 2. The key implication of the theory is that for those who are above  $c$ , if we know whether they are  $A$  or  $B$  households, income is not correlated with consumption. Fortunately, it is possible in any state to divide the households into groups  $A$  and  $B$  as households in these groups are either all making transfers or all receiving transfers. That is we can write consumption as

$$c_i = \begin{cases} \lambda + f(\kappa) & \text{if } y_i > \lambda + f(\kappa) \\ y_i & \text{if } y_i \in [\lambda - f(\kappa), \lambda + f(\kappa)] \\ \lambda - f(\kappa) & \text{if } y_i < \lambda - f(\kappa) \end{cases}$$

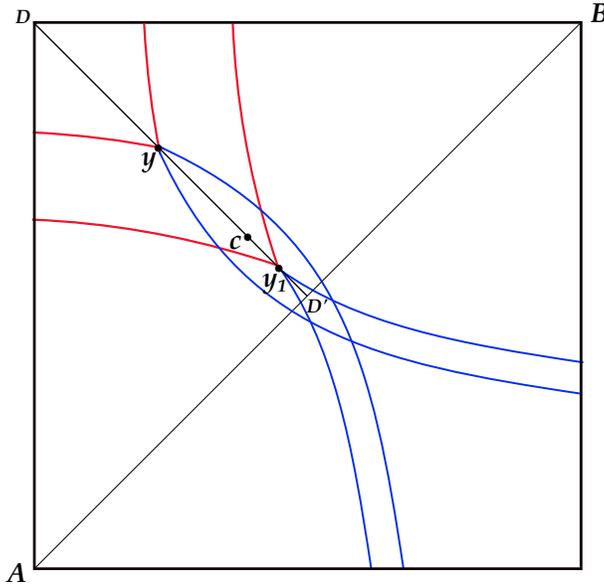
where  $\lambda$  is average income and  $f$  is an increasing function of  $\kappa$ , the degree of ambiguity. In Figure 3.3,  $c = \{\lambda - f(\kappa), \lambda + f(\kappa)\}$ .

This implication of the theory can be tested in a manner analogous to the test in [Townsend \(1994\)](#). Controlling for  $\lambda$  and  $f(\kappa)$ , consumption should be uncorrelated with income for those with income outside the set  $[\lambda - f(\kappa), \lambda + f(\kappa)]$  and perfectly correlated for those within that set. This is essentially the test proposed in this paper. The next section considers extending the discussion of this section to a more general setting.<sup>8</sup>

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<sup>8</sup>The structure of this test, which essentially looks for perfect risk sharing within two groups – the giving households and the receiving households – also suggests a novel test for the limited commitment risk sharing model of [Kocherlakota \(1996\)](#) and [Ligon et al. \(2002\)](#). In that model, risk sharing is imperfect as households with high incomes are “constrained” in their willingness to make sufficiently large transfers. Informally, households are only willing to make transfers for which they expect to receive recompense in the future. This logic implies that households receiving transfers in two consecutive periods cannot be constrained in either period and consequently, within this set of households, consumption should not be correlated with income. This test is not strictly implied by the test I present here as the fixed effects I estimate are not valid for the limited commitment model. I, therefore, leave the implementation of this test of the LC model for future work.

Figure 3.3: Empirical Implications of VEAP



### 3.3.2 General Testable Implications

The empirical test outlined above is feasible because it is possible to infer the “group” that a household is in simply by observing consumption and income in one state. This is essential as any data set will contain only a subset of the households and a subset of the states. In this section I first discuss two examples in which income in a (potentially unobserved) state implies that consumption differs among otherwise identical households, rendering the theory untestable. This discussion motivates an assumption regarding the perceived income process, which rules out this type of behavior. Given the symmetry assumptions inherent in the Edgeworth Box example, it will be no surprise that the assumption requires a degree of symmetry regarding the income process and ambiguity relative to a household’s Pareto weight. Having outlined the assumption I discuss its interpretation and show that it leads to a multi-state analog of the test discussed in the previous section.

**Example 3** (The Adding Up Problem). *Suppose there are three households  $A, B, C$ , three states of the*

world  $\{1, 2, 3\}$  and  $u = \ln$ . All households have the same Pareto weight and endowments are

$$\begin{aligned} A &= \{10, 23, 1\} \\ B &= \{10, 5, 1\} \\ C &= \{1, 2, 28\}. \end{aligned}$$

Assume that  $\Pi = \{\frac{1}{3} + \alpha, \frac{1}{3} - \alpha - \beta, \frac{1}{3} + \beta\}$  for  $\alpha, \beta \in [-\frac{1}{12}, \frac{1}{12}]$ .

A conjecture for equilibrium beliefs is that  $\alpha_A = \beta_A = -\frac{1}{12}$ ,  $\alpha_B = \frac{1}{12}$ ,  $\beta_B = -\frac{1}{12}$  and  $\alpha_C = -\frac{1}{12}$ ,  $\beta_C = \frac{1}{12}$ . This follows as household A believes that state 2 will lead to the largest loss relative to the endowment, while state 3 will lead to the greatest gain. Hence households A will choose a prior that maximizes the probability of state 2 and minimizes the probability of state 3. A similar argument applies to the other households. These beliefs lead to an optimal allocation

$$\begin{aligned} A &\approx \{5.7, 12.9, 8.2\} \\ B &\approx \{9.5, 8.6, 8.2\} \\ C &\approx \{5.7, 8.6, 13.6\}, \end{aligned}$$

and it is then possible to check that the minimizing prior given this allocation is as conjectured.

In this allocation households A and B are giving in state 1, and have the same endowment in that state, but they receive different amounts. Thus it is not feasible to run the test discussed in the previous section, the beliefs of a household are not controlled solely by income relative to the optimal consumption in a particular state. The problem occurs because in state 2, which may not be observed, household A receives a large endowment relative to B. Therefore, for A, state 2 is the most costly state while for households B state 1 is the most costly state. The requirement that the probabilities add to 1 then implies that households A and B cannot have the same beliefs in state 1 – hence the adding up problem.

**Example 4 (Optimistically Giving).** Suppose that there are three agents  $\{A, B, C\}$ , two states of the world  $\{1, 2\}$  and that  $u = \ln$ . Agent A has endowment  $\{4.75, 10\}$  agent B has endowment  $\{5.25, 0\}$  and agent C has endowment  $\{4.75, 5.25\}$ . Let  $\Pi = \{\frac{1}{2} + \alpha, \frac{1}{2} - \alpha\}$  where  $\alpha \in [-0.05, 0.05]$ .

Consider first agent C. There is a prior in  $\Pi$  such that the endowment point is preferred to any other allocation  $\{4.75 + t, 5.25 - t\}$  for all  $t$ . As a consequence C does not trade. Next consider households A and B. It seems reasonable to conjecture that state 2 will be the worst state for agent A and the best state for agent B regardless of what occurs in state 1. This in turn implies that  $\pi_2^A = 0.55$  and  $\pi_2^B = 0.45$ .

Under this assumption the social planner solves

$$\max_{\{c_1^i, c_2^i\}_{i=A,B}} \left( 0.45 \ln(c_1^A) + 0.55 \ln(c_2^A) + 0.55 \ln(c_1^B) + 0.45 \ln(c_2^B) \right),$$

subject to

$$c_1^A + c_1^B = 10 = c_2^A + c_2^B.$$

Solving this problem we find final allocations

$$\begin{aligned} c^A &= \{4.5, 5.5\} \\ c^B &= \{5.5, 4.5\} \\ c^C &= \{4.75, 5.25\}. \end{aligned}$$

Suppose that the econometrician knows the Pareto weights for the agents are  $\mu_i = \frac{1}{3}$ , then if only state 1 households  $A$  and  $C$  look identical, but do not act the same. This occurs because the endowments of  $A$  and  $C$  differ in the unobserved state 2. Household  $A$  has a very high endowment in state 2 and consequently this will be the worst state relative to the endowment even if households  $A$  actually gives money away in state 1. Hence households  $A$  is thinks a state in which it makes a transfer is likely and is “optimistically giving”. This outcome is ruled out in the Edgeworth Box example above as I impose individual rationality. That is, the contract has to be preferred to the endowment point. This is clearly not the case for the optimal contract calculated here as households 1 is making a transfer in both states.

Both examples occur due to a lack of symmetry. The adding up problem cannot occur if, for each state in which a households makes a transfer, there is a state with the same amount of ambiguity in which the household receives a transfer. Similarly, the optimistic giving example cannot occur if, for each state in which a household has an endowment “close” to the optimal, such that trade would not be optimal for some  $\alpha \in [-\kappa, \kappa]$ , there is another state for which this is also true.

To state this assumption formally, assume that the set  $S$  can be partitioned into two subsets  $S'$  and  $S''$  and that for all states  $s' \in S'$  the set  $\Pi$  is such that  $\pi_{s'} = p_{s'} + \alpha$  for  $\alpha \in [-\kappa_{s'}, \kappa_{s'}]$ . I assume the following regarding the states in  $S''$ .

**Assumption 3** (Symmetry). Let  $\hat{c}_s$  be the solution to the problem

$$\operatorname{argmax}_{c_s^i} \sum_{i=1}^N \mu_i \left( \min_{\alpha^i \in [-\kappa_s, \kappa_s]} (p_s + \alpha^i) \left( u(c_s^i) - u(y_s^i) \right) \right)$$

subject to

$$\sum_{i=1}^N c_s^i \leq \sum_{i=1}^N y_s^i.$$

For all  $s'$  there exists  $s''$  such that  $\pi_{s''} = p_{s''} + \alpha$  for  $\alpha \in [-\kappa_{s'}, \kappa_{s'}]$ , and:

1.  $\hat{c}_{s'}^i < y_{s'}^i \Leftrightarrow \hat{c}_{s''}^i > y_{s''}^i$ ;
2.  $\hat{c}_{s'}^i > y_{s'}^i \Leftrightarrow \hat{c}_{s''}^i < y_{s''}^i$ ; and
3.  $\hat{c}_{s'}^i = y_{s'}^i \Leftrightarrow \hat{c}_{s''}^i = y_{s''}^i$ .

Section 3.3.3 is devoted to the discussion of Assumption 3. That discussion shows that there are income distributions that are consistent with the assumption and gives a “psychological” interpretation of the assumption. Proposition 3 shows that Assumption 3 implies that the solution to the general programming problem (3.2) has the same simple structure as indicated by the discussion of the Edgeworth Box example.

**Proposition 3** (First Order Conditions for Optimal Risk Sharing With Ambiguity). *Given assumption 3 the first order conditions for problem (3.2) are*

$$u'(c_{is}) = \begin{cases} \frac{\lambda_s}{\mu_i(p_s + \kappa_s)} & \text{if } u'(y_{is}) < \frac{\lambda_s}{\mu_i(p_s + \kappa_s)} \\ u'(y_{is}) & \text{if } u'(y_{is}) \in \left[ \frac{\lambda_s}{\mu_i(p_s + \kappa_s)}, \frac{\lambda_s}{\mu_i(p_s - \kappa_s)} \right] \\ \frac{\lambda_s}{\mu_i(p_s - \kappa_s)} & \text{if } u'(y_{is}) > \frac{\lambda_s}{\mu_i(p_s - \kappa_s)}. \end{cases}$$

*Proof.* See Appendix E. □

The intuition for this result is straight forward, symmetry implies that whenever the social planner would like household  $i$  to make a transfer there is some other state in which the planner wishes the household to receive a transfer. The household then transfers probability mass from the receiving state to the giving state and the social planner optimizes given these beliefs.

### 3.3.3 A Discussion of Assumption 3

The assumption essentially has three parts.

1. For all states  $s'$ , there is an equivalent state  $s''$  that is equally ambiguous.
2. If state  $s'$  is sufficiently ambiguous so households  $i$  would not benefit from trade at state  $s'$ , then this is also the case in state  $s''$ .

3. If state  $s'$  is such that household  $i$  will make (receive) a transfer, then households  $i$  will receive (make) a transfer in state  $s''$ .

The combination of the first and second parts rules out Example 4 while the combination of Part 1 and 3 rules out Example 3. The assumption is consistent with a situation in which two households have perfectly negatively correlated incomes, equal Pareto weights and income distributions that are symmetric with respect to ambiguity.

Assumption 3 is also consistent with the following psychological interpretation. There are a set of rainfall states  $R$  and for each rainfall state there are two possible outcomes  $\phi_1$  and  $\phi_2$ . In state  $\phi_1$  incomes are given by some state  $s' \in S'$  while in state  $\phi_2$  incomes are given by the equivalent state  $s'' \in S''$ . The household does not know exactly the probability of sub-states  $\phi_1$  and  $\phi_2$  but  $p(r, \phi_1) \in [p_r - \kappa_r, p_r + \kappa_r]$ . The psychology of this interpretation is as follows. For each rainfall state there are unknown correlates  $\phi$  (perhaps locusts as in Maggie's example) which mean that the household believes there are two possible village income distributions determined by  $\phi_1$  and  $\phi_2$ . Further, these distributions are opposite, in the sense that in one the household believes they will be making a transfer and in the other they will be receiving a transfer. Under this interpretation it seems natural to view  $\kappa_r$  as being related to the rarity of the rainfall state  $r$ . If state  $r$  is observed often the households have enough information to form a prior regarding state  $\phi_1$  and  $\phi_2$  so  $\kappa_r$  is small. On the other hand, if state  $r$  is rarely observed, households may have no idea whether they will be giving or receiving transfers, implying that  $\kappa_r$  is large.

While the symmetry assumption is extreme it leads to particularly simple testable implications that have some intuitive appeal. Further, the resulting test is simple to implement and has a close relationship to the usual tests of risk sharing. It is likely that similar implications can be derived under less restrictive assumptions, but I leave the question to future research.

### 3.3.4 Estimating Equations and Empirical Approach

I follow much of the risk sharing literature and assume that  $u$  is either CARA.<sup>9</sup> With this assumption the first order conditions in Proposition 3 can be rewritten

$$c_{is} = \begin{cases} \ln \mu_i - \ln \lambda_s + \ln(p_s - \kappa_s) & \text{if } y_{is} < \ln \mu_i - \ln \lambda_s + \ln(p_s - \kappa_s) \\ \ln \mu_i - \ln \lambda_s + \ln(p_s + \kappa_s) & \text{if } y_{is} > \ln \mu_i - \ln \lambda_s + \ln(p_s + \kappa_s) \\ y_{is} & \text{otherwise.} \end{cases}$$

---

<sup>9</sup>A CRRA assumption leads to a specification in logs. I have not pursued that specification at this stage.

This motivates an empirical specification

$$c_{ivt} = \begin{cases} \hat{\mu}_{iv} + \hat{\lambda}_{vt} - \hat{\kappa}_{vt} + \epsilon_{ivt} & \text{if } y_{ivt} < \hat{\mu}_{iv} + \hat{\lambda}_{vt} - \hat{\kappa}_{vt} \\ \hat{\mu}_{iv} + \hat{\lambda}_{vt} + \hat{\kappa}_{vt} + \epsilon_{ivt} & \text{if } y_{ivt} > \hat{\mu}_{iv} + \hat{\lambda}_{vt} + \hat{\kappa}_{vt} \\ y_{ivt} + \epsilon_{ivt} & \text{otherwise} \end{cases} \quad (3.3)$$

where subscript  $v$  refers to the village,  $\hat{\mu}_{iv}$  is a household fixed effect,  $\hat{\lambda}_{vt}$  is a village year fixed effect capturing village levels shocks,  $\hat{\kappa}_{vt}$  is a village year fixed effect capturing the degree of ambiguity in the state realized in village  $v$  at time  $t$  and  $\epsilon_{ivt}$  is a mean zero measurement error in consumption.

The fundamental implication is that once  $\hat{\lambda}$ ,  $\hat{\mu}_i$  and  $\hat{\kappa}$  are controlled for, income does not affect consumption for those who are trading, and for those who are not trading, income perfectly predicts consumption. My empirical strategy is to test this assertion by estimating the model

$$c_{ivt} = \begin{cases} (1 - \alpha)(\hat{\mu}_{iv} + \hat{\lambda}_{vt}) + (\beta - \alpha)\hat{\kappa}_{vt} + \alpha y_{ivt} + \epsilon_{ivt} & \text{if } y_{it} > \hat{\mu}_{iv} + \hat{\lambda}_{vt} + \hat{\kappa}_{vt} \\ (1 - \alpha)(\hat{\mu}_{iv} + \hat{\lambda}_{vt}) - (\beta - \alpha)\hat{\kappa}_{vt} + \alpha y_{ivt} + \epsilon_{ivt} & \text{if } y_{ivt} < \hat{\mu}_{iv} + \hat{\lambda}_{vt} - \hat{\kappa}_{vt} \\ (1 - \beta)(\hat{\mu}_{iv} + \hat{\lambda}_{vt}) + \beta y_{ivt} + \epsilon_{ivt} & \text{otherwise.} \end{cases} \quad (3.4)$$

The empirical content of the theory is that there exist numbers  $\hat{\lambda}$ ,  $\hat{\kappa}$  and  $\hat{\mu}$  such that, once these are controlled for,  $\alpha = 0$  and  $\beta = 1$ . From this perspective, it does not matter how the numbers  $\hat{\lambda}$ ,  $\hat{\kappa}$  and  $\hat{\mu}$  are calculated, merely that they exist. My chosen estimation method is to use non-linear least squares.<sup>10</sup>

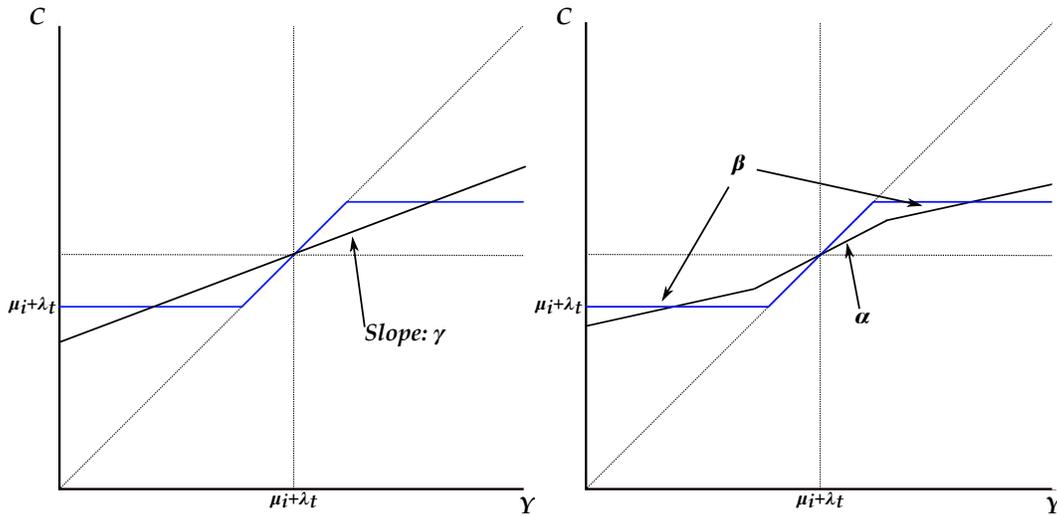
Figure 3.4 presents a graphical illustration of both the empirical strategy and why ambiguity aversion can explain the correlation between consumption and income. The figure shows observations from a particular household. The blue piecewise linear line in both panels represents the model (3.3). Tests of risk sharing typically run regressions of the form

$$c_{it} = \mu_i + \lambda_t + \gamma y_{it} + \eta_{it}. \quad (3.5)$$

The black line in the left panel shows the fitted values from this regression if the data is generated by (3.3) and there is no heterogeneity in  $\kappa$  over time. The regression will find a positive estimate of  $\gamma$  reflecting the “wedge” created by ambiguity. The black line in the right panel illustrates the possible outcome from estimating (3.4). If the true model of the world is (3.3) then the estimates will show  $\alpha = 0$  and  $\beta = 1$ . If, on the other hand, if the kink generated by ambiguity is insufficient to explain the positive correlation between consumption and income

<sup>10</sup>Related to this discussion one may wonder whether the process is mechanically able to fit the data. This is not the case as shown by the fact that the process does not fit the data in at least one of the ICRISAT villages.

Figure 3.4: Tests of Risk Sharing



the estimates will show  $\alpha > 0$  and/or  $\beta \neq 1$ .

### 3.4 Relation to the Literature

#### 3.4.1 No Trade and Ambiguity

The possibility that ambiguity aversion (or Knightian uncertainty) could lead to a failure to trade was first formalized in [Bewley \(1989\)](#). That paper points out the importance of the kink at the endowment. Specifically, [Bewley \(1989\)](#) argues that [Gilboa and Schmeidler \(1989\)](#) preferences cannot explain missing insurance markets. This observation motivates the use of VEA preferences.<sup>11</sup> [Rigotti and Shannon \(2005\)](#) further analyze that model in a general equilibrium setting. This paper is motivated by those two papers.

#### 3.4.2 The Empirical Risk Sharing Literature

Beyond explaining the results of [Townsend \(1994\)](#), the model of [Section 3.2](#) can explain two other empirical features found in the literature. First, several papers, most notably [Fafchamps and Lund \(2003\)](#), argue that risk-sharing takes place predominantly among members of smaller

<sup>11</sup>See, however, [de Castro and Chateauneuf \(2008\)](#) who argue that [Gilboa and Schmeidler \(1989\)](#) can account for an absence of trade if the endowment is unambiguous.

“networks” rather than the entire village. However, if members of the same risk-sharing network have correlated incomes, then the VEA model implies they will appear to share risk more effectively. This occurs because they are more likely to be in the same group – giving or receiving.<sup>12</sup>

Second, [Mazzocco and Saini \(2009\)](#) show that full risk sharing with heterogeneous risk preferences can be rejected in the ICRISAT villages because pairwise expenditure functions are not monotonic. This result is, however, consistent with risk sharing in the presence of ambiguity aversion. Consider a pair of households  $A$  and  $B$  and two states of the world. In the first state of the world household  $A$  is giving and  $B$  receiving. In the second state, aggregate income is higher and household  $A$  is receiving and  $B$  is giving. If there is sufficient ambiguity, consumption of household  $B$  can be lower in the second state of the world, despite the fact that aggregate income is higher.

### 3.5 Data

The data is taken from two data sets. First, I use the ICRISAT vls data set. I use consumption and income measures computed as in [Townsend \(1994\)](#) and similar to that paper concentrate on the three villages (Aurepalle, Shirapur and Kanzara) that were continuously interviewed for 10 years. This decision is motivated by the need to accurately estimate the  $\mu_i$ .

I also use data from the Townsend Thai Monthly panel. I use the same measures of income and consumption as [Kinnan \(2010\)](#) and, like that paper, aggregate the monthly observations to create yearly observations. The method of constructing these measures is discussed in detail in [Samphantharak and Townsend \(2009\)](#). I use income constructed according to the accrual method as outlined in that monograph.

### 3.6 Results

I estimate (3.4) using non-linear least squares. Tables 3.1 and 3.2 present the results for the ICRISAT and Townsend Thai villages respectively. In both tables all villages are pooled, but as indicated in (3.4) I allow for villages to have different aggregate shocks and ambiguity levels.

The first column of Tables 3.1 and 3.2 presents the familiar test for perfect risk sharing. I run

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<sup>12</sup>[Bryan \(2008\)](#) provides a similar argument in the context of limited commitment risk sharing. That paper shows that if risk sharing is characterized by limited commitment and incomes are correlated within network then the test proposed by [Fafchamps and Lund \(2003\)](#) will spuriously conclude that networks are important for risk sharing.

Table 3.1: NLLS Estimates of the Impact of Income on Consumption: ICRISAT

	Townsend Test	Non-Linear Model		
	1	2	3	4
Alpha	0.109*** (0.026)	- -	0.016 (0.029)	0.000 (0.030)
Beta	- -	- -	1.221*** (0.309)	- -
N	1040	1040	1040	1040
R <sup>2</sup>	0.591	0.623	0.623	0.623
SSE/10000	761.021	701.433	697.847	701.432

\*\*\*  $\Rightarrow p < 0.01$ , \*\*  $\Rightarrow p < 0.05$ , \*  $\Rightarrow p < 0.1$ . Standard errors in parentheses.

the regression

$$c_{ivt} = \mu_{iv} + \lambda_{vt} + \gamma y_{ivt} + \eta_{ivt}, \quad (3.6)$$

and consistent with [Townsend \(1994\)](#) for the ICRISAT villages and [Kinnan \(2010\)](#) for the Townsend Thai data, I find that the estimate of  $\gamma$  is positive and significant. The second column presents the sum of squared errors for non-linear least squares estimates of (3.3). The intuition presented in [Figure 3.4](#) implies that if the kink caused by  $\kappa$  is a reasonable explanation of the excess sensitivity of consumption to income, then it must be the case that the sum of the squared errors for estimating (3.3) should be less than that from estimating (3.6). The table shows that this is the case for both data sets.<sup>13</sup>

Next, Column 3 in each of the tables presents the NLLS estimates of (3.4). It is not possible to reject the hypothesis that  $\alpha = 0$  nor the hypothesis that  $\beta = 1$  for either of the data sets and the estimate of  $\beta$  is in both cases substantially smaller than the estimate of  $\gamma$  in Column 1. It should be noted that while  $\beta = 1$  cannot be formally rejected, it is noisily estimated, particularly in the ICRISAT data. Finally, Column 4 re-estimates (3.4) constraining  $\beta$  to be equal to 1. The logic

<sup>13</sup>This is necessary for the VEA explanation to be relevant, but because the year specific  $\kappa$  essentially allow year specific slopes it is not sufficient to conclude that the model is correct.

Table 3.2: NLLS Estimates of the Impact of Income on Consumption: Townsen

	Townsend Test	Non-Linear Model		
	1	2	3	4
Apha	0.023*** (0.003)	- -	0.002 (0.003)	0.002 (0.003)
Beta	- -	- -	1.057*** (0.079)	- -
N	4700	4700	4700	4700
R <sup>2</sup>	0.622	0.661	0.662	0.662
SSE / 10000000	704.35	633.19	632.92	631.72

\*\*\*  $\Rightarrow p < 0.01$ , \*\*  $\Rightarrow p < 0.05$ , \*  $\Rightarrow p < 0.1$ . Standard errors in parentheses.

for including this test is that if  $\beta$  is overestimated it may spuriously lead to a low estimate of  $\alpha$ . Once again it is not possible to reject the hypothesis that  $\alpha = 0$ .

Overall the results seem to be compelling that allowing for the non-linear effect of  $\kappa_{vt}$  implies that there is little remaining correlation between consumption and income. Much of the evidence on the ICRISAT villages has, however, been presented on a village by village basis.<sup>14</sup> In the interests of a complete comparison to the literature, I therefore estimate the model separately for each of the ICRISAT villages. The results are presented in Table 3.3. The results show that for Aurepalle and Shirapur the estimates of  $\alpha$  are almost identical to zero. For these two villages I conclude that there is very little remaining correlation between consumption and income once ambiguity is controlled for. For Kanzara, in contrast, controlling for ambiguity has little impact and the estimate of  $\alpha$  is extremely close to the estimate of  $\gamma$  from the traditional test of complete risk sharing. To be frank, I have no explanation for the differences between the villages. The disaggregated results simultaneously increase confidence in the model by showing the good fit for Aurepalle and Shirapur, but reduce confidence by showing that Kanzara's consumption income dynamics clearly cannot be explained by the model. The results also im-

<sup>14</sup>See for example Townsend (1994), Ligon (1998) and Ligon et al. (2002).

Table 3.3: NLLS Estimates of the Impact of Income on Consumption: ICRISAT by Village

	Aurepalle			Shirapur			Kanzara		
	1	2	3	1	2	3	1	2	3
Alpha	0.139*** (0.053)	0.000 (0.052)	0.000 (0.058)	0.127** (0.054)	0.006 (0.069)	0.002 (0.070)	0.303*** (0.067)	0.269*** (0.073)	0.251*** (0.074)
Beta	- -	1.051 (0.677)	- -	- -	1.087*** (0.366)	- -	- -	1.499 (0.936)	- -
Const	146.6 (123.600)	212.588* (111.236)	212.588* (123.310)	798.10*** (115.600)	876.91*** (120.057)	876.21*** (119.382)	407.4*** (103.000)	465.5*** -170.2	560.1** -223.1
N	210	210	210	198	198	198	216	216	216
R <sup>2</sup>	0.643	0.689	0.688	0.712	0.736	0.736	0.709	0.731	0.73
SSE/10000	135.490	117.931	118.343	106.076	97.138	97.288	88.000	81.300	81.600

\*\*\*  $\Rightarrow p < 0.01$ , \*\*  $\Rightarrow p < 0.05$ , \*  $\Rightarrow p < 0.1$ . Standard errors in parentheses.

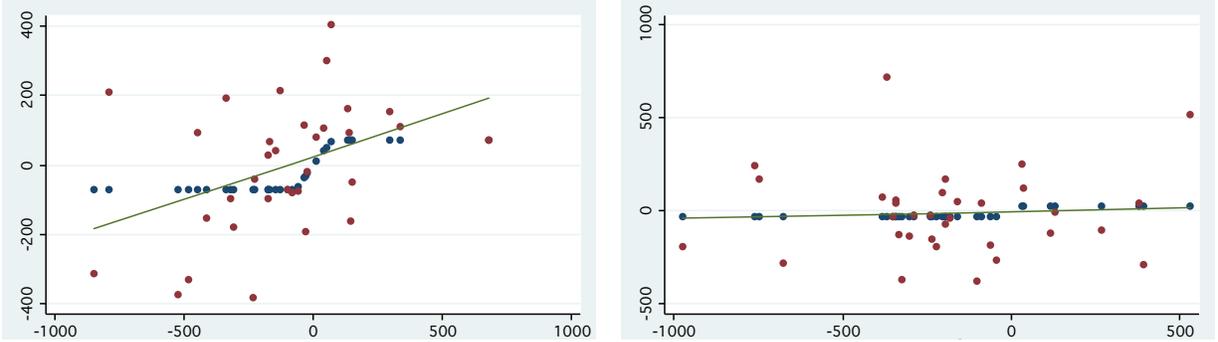
ply that the results are in general not driven by a mechanical ability to fit any data set with the NLLS model.

Overall the results show that it is not possible to reject the VEA model, but one may wonder whether other models have similar implications. In particular the results may seem to be consistent with trade costs. One fact suggests that this is not the case. Figure 3.5 shows empirical plots of consumption against income for two years in Shirapur. The left panel shows 1976 and the right 1978. In both cases the red dots are the data and the blue dots fitted data points from the VEA model. The solid green line is a line of best fit. If trade costs is the true explanation, one would have to explain why risk sharing appears to be so bad in 1979, but so good in 1976 despite the similar spread in incomes. This turns out to be quite a general finding in both data sets. In many years  $\kappa_t$  is estimated to be large and significant, but for perhaps an equal number of years  $\kappa_t$  is small and insignificant. Explaining this fact would appear to require year specific trade costs. In contrast ambiguity aversion provides a natural explanation in terms of how rare the rainfall event was. I intend to test this implication in future work.

### 3.7 Conclusion

In this section I showed evidence that consumption and income patterns in both the ICRISAT and Townsend Thai monthly data sets are consistent with a model of ambiguity aversion. I

Figure 3.5: Consumption Income Plots for Shirapur 1976 and 1979.



Left panel; Shirapur 1976. Right panel: Shirapur 1979.  $y$ -axis measures consumption,  $x$ -axis income. Clustered light grey dots show predicted values from NLLS regression 3.4. Dark grey dots show the raw data. The solid line presents a line of best fit.

conclude from this evidence that ambiguity aversion is a sufficient explanation for incomplete risk sharing. I see this result as an encouraging first finding in a larger research project. In particular the theory seems to have several additional implications.

First, as discussed above, Figure 3.5 highlights that risk sharing in both data sets is close to complete in some years, and far from complete in other years. Section 3.3.3 suggests a psychological interpretation of the VEA model that naturally accommodates this fact and also suggests that the estimates  $\kappa_{vt}$  should be correlated with the rarity of the rainfall event in village  $v$  at time period  $t$ . Testing this implication requires two hurdles to be crossed. First, it requires a long time series of rainfall data for the affected villages from which it is possible to construct measures of rarity. This data is almost certainly available for India, although it is not clear whether it is sufficiently disaggregated. Second, it requires that the  $\kappa_{vt}$  be identified. As discussed above, this is not required for the test presented above, which requires only that some  $\kappa_{vt}$  exist. It is not clear, however, that the NLLS estimation used to find the  $\kappa_{vt}$  produces unique results.

Second, as argued in Section 3.4 the VEA model provides an explanation for the empirical finding the risk sharing is better in networks. The caste measure in the ICRISAT data provides a natural measure of the risk sharing network that has been exploited by several authors in the past. A simple test of the theoretical claim is to consider whether households of particular castes are “more likely” than average to be in the same group – receiving, giving or not trading.

Third, as discussed in Section 3.4 the VEA model can explain the finding of Mazzocco and Saini (2009) that pairwise expenditure functions cross. The explanation given was that households swapping between giving and receiving may experience changes in consumption large enough to overcome the impact of increase pairwise income. It seems plausible to test this im-

plication given that the NLLS routine identifies households as either giving or receiving, and also the change in ambiguity between time periods.

Fourth, and more ambitiously, many of the implications of the model carry through to a model with heterogeneous ambiguity attitude. As both the ICRISAT and Townsend Thai villages are still active research sites, an obvious research direction is to elicit ambiguity attitude from these households and to use this information in conjunction with the model to determine whether ambiguity averse households engage in less risk sharing.

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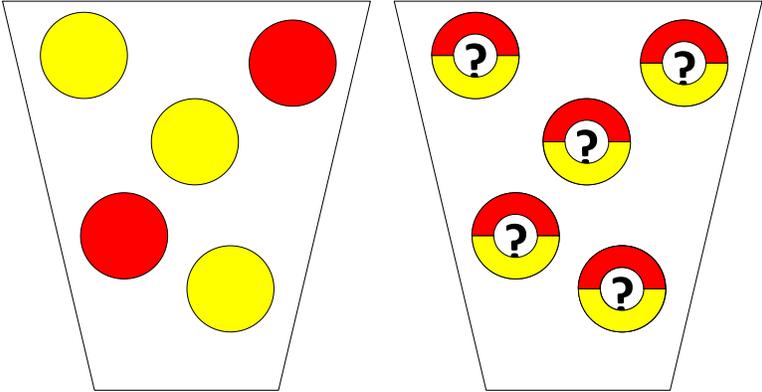
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# A Visual Aids

The following visual aid was given to respondents when asked Question 1.



Bag 1

Bag 2

## B Risk Aversion Questions

Respondents were given the following hypothetical questions.

**Question 2** (Measuring Risk Aversion – Kenya). *Imagine you are going to flip a coin and you win if it lands on heads and you also win if it lands on tails. However, the amount you win depends on the bet you choose. Given the following, which bet would you choose:*

1. 1000/1000
2. 900/1900
3. 800/2400
4. 600/3000
5. 200/3800
6. 0/4000

**Question 3** (Measuring Risk Aversion – Malawi). *You are going to play a game, I am going to flip a coin. Imagine that you would get the money shown under the GREEN area if it lands on heads or the money shown under WHITE area if it lands on tails. The amount you would win depends on the bet you choose. Which bet would you choose?*

1. 50 / 50
2. 40 / 120
3. 30/160
4. 20 / 190
5. 10 / 210
6. 0/220

The visual aid contains photos of the monetary amounts.

# C The General Model of Index Insurance and Technology Adoption

Please see <http://www.econ.yale.edu/~gtb3> for latest version.

## D Dynamic Ambiguity Averse Choice

The dynamic extension of ambiguity averse preferences is the subject of a large and unsettled literature (see, for example, [Gilboa and Schmeidler 1993](#), [Epstein and Schneider 2003](#), [Hanany and Klibanoff 2007](#) & [Siniscalchi 2006](#)). Here I discuss assumption that allow for learning but imply that choices will essentially be the same as those in the static setting. I also discuss the implications of those assumptions for both the empirical and policy implications of the paper.

There are three reasons why dynamic considerations alter technology adoption decisions. First, in the presence of credit constraints, wealth at time  $\tau$  will determine the likelihood of adoption. Consequently, the impact of a decision in time period  $t < \tau$  must take in to account the impact on future wealth. I rule this out by assuming that there are no credit constraints. It is unlikely that this will have any implications for the results. Second, ambiguity averse preferences have the potential to be time-inconsistent. [Example 5](#) illustrates.

**Example 5** (A Commitment Problem). *Consider again the setting from [Example 1](#) but assume that the decision is repeated  $T$  times with balls drawn with replacement. Denote  $WA$  the choice of the white ball from the ambiguous urn and  $R$  the choice of the risky urn. The objects of choice are sequences, for example  $\{R, WA, R, BA, \dots, R\}$ . Let  $\pi$  be an assessment of the likelihood that a white ball will be chosen from the ambiguous urn and assume that  $\pi \in \Pi = [0.4, 0.6]$  so that the decision maker is ambiguity averse. Finally, to concentrate on the impact of dynamics on ambiguity averse decision making assume that the agent does not learn and therefore  $\Pi$  remains unchanged over time. How should this decision maker choose?*

There are two different intuitions for this problem. The first suggests that ambiguity can be “hedged” by choosing and committing to a string of choices  $\{WA, BA, WA, BA, \dots\}$ . This can be modeled by assuming that the decision maker will choose the ambiguous urn so long as

$$\min_{\pi \in \Pi} \left( \sum_{t=1}^T \delta^{t-1} \left[ \pi W_t + (1 - \pi)(1 - W_t) \right] \right) \geq \sum_{t=1}^T \delta^{t-1} \frac{1}{2} \quad (\text{D.1})$$

where  $W_t$  is an indicator taking on value 1 if  $WA$  is chosen in period  $T$ .<sup>1</sup> Under this criterion, as  $\delta \rightarrow 1$ , the ambiguous urn becomes indifferent to the risky urn regardless of the size of the set  $\Pi$  (so long as  $T$  is even). Consequently the effect of ambiguity aversion tends to go away when the dynamic problem is considered.

There is, however, a problem with criterion (D.1). Suppose that the agent is given the choice at time period  $T$  to rethink his choice. Given the assumption that there is no learning, he will almost certainly

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<sup>1</sup>The agent is assumed to be risk neutral as this highlights the problem more starkly.

choose  $R$ , consistent with his initial choice in the Ellsberg example. However, given this choice in period  $T$ , he would also like to change his choice in period  $T - 1$  and so forth. This discussion suggests an alternative decision criterion where the ambiguous urn is chosen in period  $t$  if

$$\min_{\pi \in \Pi} \left( \pi W_t + (1 - \pi)(1 - W_t) \right) \geq \frac{1}{2}. \quad (\text{D.2})$$

Criterion (D.2) essentially says that the agent will behave according to backward induction and because the inequality never holds in this example the agent continues to display aversion to ambiguity in this dynamic problem.

I adopt criterion (D.2) for the purposes of policy discussion. The implications of this choice for the empirical tests depends on what farmers assumed regarding the future availability of insurance. If those offered insurance felt that it would be available in the future then the empirical tests in this paper essentially test between criteria (D.1) and (D.2). However, if farmers believed that the insurance would be offered for only one period then (D.1) and (D.2) give the same empirical implications.

The assumption is, however, essential for policy recommendations. In practice, if index insurance is made available it is likely to be over a long term and agents might be able to engage in the sort of “hedging” described in Example 5. What little evidence there is on time consistency and decision making under ambiguity suggests that agents are likely to display time inconsistency and decide according to backward induction (see Dominiak et al. 2009). The much larger literature on commitment, time inconsistency and hyperbolic discounting also lends support to the idea that individuals lack the ability to commit to future decisions and tends to lend support to the use of criterion (D.2) (see for example Strotz 1956, Laibson 1997, Ashraf et al. 2006 and for a review Bryan et al. 2010).

The third reason why dynamic decision making may differ from static decision making is that agents learn, and they value the opportunity to learn. There is therefore a tradeoff between current payoffs and learning about the new technology. This tradeoff is usually captured by the multi-armed bandit model (see Bergemann and Valimaki 2008 for a review). It is possible that this strategic approach to learning will have different implications for those who are ambiguity averse as suggested by the following example.

**Example 6** (An Ellsberg One-Armed Bandit). *Suppose first that the setting is as in Example 5 but that there is no color choice – the agent wins if a white ball is drawn. Assuming that the agent makes use of criterion (D.2) in each period then she should experiment with the ambiguous urn only if it is worthwhile for all of her beliefs  $\pi \in [0.4, 0.6]$ , but this is never the case. With  $p = 0.4$  she will lose now and believes that it is not worthwhile to experiment. In this case caution with respect to current outcomes and caution with respect to learning imply the same thing – don’t move from the status-quo.*

*Next consider the case where the agent can choose in each period between white and black. It can be shown that under plausible assumptions an AA agent believes that her preferences will eventually converge to some singleton  $\tilde{\pi} \in \Pi$ . Further, as discussed above, for all singleton priors such as  $\tilde{\pi}$  the ambiguous urn must be weakly preferred. Therefore, the introduction of the option to choose the black ball implies that it is no longer possible for the agent to be pessimistic with respect to learning. In particular, caution with respect to her current choice of WA would lead her to believe that she will almost certainly learn that BA is a good choice for the future.*

As the addition of insurance is akin to the provision of the ability to select the black ball, this example tends to suggest that the provision of insurance will improve the perceived benefits of learning for an ambiguity averse agent.

Despite this intuition, there have (to the best of my knowledge) been no formal studies of the multi-armed bandit model with ambiguity averse preferences. It is therefore unclear how general the intuition in Example 6 is. There are, however, several reasons to believe that AA agents will not be greatly affected by strategic learning. First, the experimental evidence on multi-armed bandit problems tends to suggest that people under experiment relative to the Bayesian optimum (see [Meyer and Shi 1995](#) and [Gans et al. 2007](#)). Second, the amount of time required to learn the distribution is probably large (estimated to be in the order of twenty years in the results section) and learning is therefore slow. Given a reasonable discount rate, it is unlikely that strategic learning will play a large role in current decisions. Third, the updating rule in Example 6 is complicated and it is questionable whether people reason in this much depth. For these reasons it seems reasonable to rule out strategic learning when discussing policy implications.

Finally, if the assumptions in this section are incorrect and dynamic considerations change the implications of ambiguity aversion for insurance, this paper can be seen as making a methodological point on the implementation of randomized control trials to assess the impact of insurance products. Specifically, if dynamic considerations are essential to the demand for insurance then evaluations must ensure that participants believe that the insurance product will be offered over a long period of time.

## **E Proof of Proposition 3**

Please see <http://www.econ.yale.edu/~gtb3> for latest version.