The Farmer and The Fates: Locus of Control and Investment in a Stochastic Production Process

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Abstract

Economists and policy makers alike often find themselves struggling to explain low levels of adoption for seemingly profitable agricultural technologies. This easily extends to technologies that stabilize yields in the face of weather and pest pressure. In this paper, I take a behavioral approach to explaining adoption and investment rooted in the psychological notion of locus of control, which captures the extent to which a decision-maker believes that her actions affect outcomes relative to forces outside of her control. I consider how locus of control affects neoclassical models of decision-making and test various pathways using primary data from smallholding farmers in Eastern Africa. In addition to a standard locus of control instrument from psychology, I develop a measure of locus of control specific to maize production. I show that farmers with more external locus of control are significantly less likely to adopt improved maize varieties. Using data on subjective weather expectations and risk attitudes, I present suggestive evidence that locus of control is not reflecting differences in preferences or subjective probabilities, but rather affecting beliefs about the production function itself.

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1 Introduction

Despite the seemingly high returns to agricultural technologies that improve yields and reduce exposure to weather risk, their adoption by the most vulnerable households is often low. In the combined sample of farm households from Mozambique and Tanzania surveyed for this paper, less than half report using any improved seed variety and only five percent report using chemical fertilizers. While these low levels of adoption may speak to issues of access, they do not result from a lack of innovation. In 2016 alone, the CGIAR Research Program MAIZE (MAIZE CRP) had a budget of 11.6 million dollars focused on developing and promoting stress-resistant and nutritious maize varieties (CGIAR, 2016). Drought Tolerant Maize for Africa (DTMA), one of the MAIZE CRP's flagship programs, released twenty drought tolerant maize varieties in Tanzania and nine in Mozambique between 2007 and 2015[1] (CIMMYT, 2015). Among the remote, resource-poor and drought-exposed households in this study, however, use of drought-tolerant maize seed was practically non-existent.

The very environment that creates a need for technologies such as drought-tolerant maize may play a key role in inhibiting their adoption. Since the 1950s, research in psychology has noted that locus of control, the extent to which a decision-maker believes that outcomes are determined by her actions relative to forces outside of her control, is an important component of behavior and learning (Lefcourt, 1982). Repeated exposure to negative shocks – such as crop failure due to severe drought – may create in decision-makers the sense that their investment is dwarfed by the influence of external forces.

While this paper will focus primarily on agriculture, the idea that previous exposure to shocks may limit the willingness of vulnerable individuals to make future investments is broadly applicable. Many innovations are expressly designed to increase economic resilience in the face of risk, which as been shown to tax physical resources (Carter et al., 2007) and cognitive function (Mani et al., 2013). If exposure to that same risk also creates enduring attitudes that limit the uptake of risk-coping technologies then promoting stability becomes much more challenging.

In this paper, I study the conceptual link between locus of control and neoclassical choice and test the resulting insights empirically. Neoclassical choice theory sets out clear conditions for optimal behavior. In order to be incorporated into this theory, locus of control must influence a subjective element present in these conditions: preferences, probabilities, or production functions. As a belief about the input-output relationship, the intuitive pathway

[1]In total, 233 drought-tolerant maize varieties were released across thirteen countries in sub-Saharan Africa over the period 2007 - 2015.

seems to be that locus of control would influence subjective beliefs about the production function.

I use primary data from a large sample of maize-producing households in Eastern Africa to empirically test the influence of locus of control on investment. Specifically, I focus on the adoption of improved maize seed varieties in a sample of around 3,000 households from Mozambique and Tanzania. This population is ideal for studying the relationship between locus of control and investment in risky environments. Efforts such as those by CIMMYT's DTMA project have helped create technologies that seek to increase and stabilize maize production. At the same time, frequent drought and limited access to financial services have contributed to high levels of food insecurity and other shocks that might lead decision-makers to believe that external forces dominate their decisions in determining outcomes. In addition to standard measures, I develop a survey instrument for locus of control specific to maize production to more closely reflect the influences suggested in the psychology literature.

I show that farmers exhibiting a more external locus of control – those who believe that the variability in maize harvest associated with adopting improved maize varieties is small relative to the variability in harvest associated with weather outcomes – are significantly less likely to adopt improved maize varieties. The size of this effect is non-trivial: between four and eleven percent. These households are also shown to be less likely to adopt drought-tolerant maize varieties in response to a randomized marketing intervention.

In support of the hypothesized pathway, I demonstrate that there is a strong relationship between locus of control and the expected return to adopting improved seed varieties. I show that this is not a mechanical function of the newly developed survey instrument, but rather a deeper connection between the locus of control construct and the subjective production function. I also show that in the current sample, locus of control is not strongly related to either subjective expectations about weather patterns or risk attitudes.

2 Locus of Control and Economics

Locus of control – where or with whom control of outcomes lies – denotes the location of an individual's beliefs along a spectrum from internal to external (Rotter, 1966). While belief about the influence of internal and external forces can be elicited separately, locus of control is often described as the balance between them. An internal locus of control reflects the belief that one's own actions are a primary force in determining outcomes. External locus of control, on the other hand, is the belief that outcomes are principally determined by external forces.

The construct traces its roots to the early twentieth century and the social learning theories published in Julian Rotter's *Social Learning and Clinical Psychology* (1954). North American psychology at the time was dominated by the behaviorist paradigm, most famously associated with Ivan Pavlov and John B. Watson, which viewed the stimulus-response relationship as essentially mechanical (Miller, 2003). Rotter's work was part of what became known as the cognitive revolution, whereby the behaviorist paradigm was rejected in favor of theories that took mental processes more seriously.

Rotter hypothesized that a decision-maker's locus of control would affect how she acted and what she learned from her experiences. Early experiments with non-human subjects had shown that exposure to inescapable, negative stimuli resulted in reduced avoidance behavior and slower learning when stimuli were eventually made avoidable (Lefcourt, 1982). In essence, external locus of control could be induced and had persistent effects on learning and behavior. Researchers quickly noted that life itself administers to humans a host of stimuli, some postive, some negative, and many inescapable. As a result, differences in locus of control were shown to exist among various populations, particularly those exposed to high levels of risk at early ages. Race, socioeconomic class (Lefcourt and Ladwig, 1965; Battle and Rotter, 1963), and residence in urban versus rural areas (Nelsen and Frost, 1971) were all associated with differences in expectations about one's ability to control outcomes.

Psychologists also linked locus of control to many behavioral outcomes, including decision-time, stress coping, and academic performance (Franklin, 1963; Mc Ghee and Crandall, 1968; Bar-Tal and Bar-Zohar, 1977). In one of the most significant results, beliefs akin to internal locus of control were found to be the best predictor of achievement in underprivileged child populations (Pettigrew, 1967; Coleman, 1971).

A number of the above outcomes, such as academic effort and achievement, can be thought of as economic behavior. While the primary application throughout this paper will be rainfed agriculture, locus of control is relevant to a broad set of topics. Any economic process in which outcomes are a function of both agent decisions and external forces has an intuitive connection to locus of control. This is particularly true when the external influences are not clearly observable. In such processes the returns to one's own actions are difficult, if not impossible, to clearly identify, paving the way for subjective beliefs to play an active and persistent role in decision-making.

Locus of control can capture attitudes about life broadly or it can be framed with respect to a particular activity domain. I will refer to a decision-maker's beliefs about her ability to influence outcomes in life broadly as her general locus of control. Activity specific locus of control, then, will refer to a decision-maker's beliefs about her ability to control outcomes in a more narrowly defined activity, such as agriculture. In his 1975 review of research into the construct, Rotter likened the distinction between general and activity specific locus of control to having beliefs about the forces that controlled outcomes in education and in a psychology course respectively (Rotter, 1975).

Cumulative interaction with one's environment – a decision-maker's experiences, the shocks she has faced, her challenges and successes – are codified into general locus of control. When facing an activity that is new or relatively unknown, Rotter posited, decision-makers will lean more heavily on this general belief. As experience accumulates, a more refined belief will be formed about the decision-maker's ability to influence outcomes in the activity. As such, locus of control represents current attitudes toward causality and not an immutable personality trait. As one author put it, an internal locus of control might well be described saying:

> *"Those who report (on a given scale) that they perceive events as being largely contingent upon their personal efforts at the present time, as opposed to those who feel more fatalistic about the manner in which outcomes occur."*
> (Lefcourt, 1982)

Locus of control is not entirely new to economics, though it is far from prominent. Savings behavior (Cobb-Clark et al., 2016), labor market outcomes (Cobb-Clark, 2015; McGee, 2015), and selection into job training programs (Caliendo et al., 2016) have all been studied in relation to locus of control. Additionally, Coleman and DeLeire (2003) study the impacts of locus of control among eighth-grade students on their subsequent educational attainment. Most closely related to this paper is the work of Laajaj et al. (2017), which compares locus of control to a host of cognitive and non-cognitive skills and agricultural behavior in Kenya, and the work of Abay et al. (2017) which relates general locus of control to agricultural behavior in Ethiopia. Both papers find what the authors of Abay et al. (2017) call "empirical regularities" between locus of control and investment in agriculture.

While the intuitive connection between locus of control and investment is clear, the construct itself does not map directly into an analytical framework. While it may describe a relationship between the returns to own actions and the returns to external forces, it is not precisely defined as one or the other. This challenge is made greater by the near exclusive use in the existing literature of general locus of control measures.

2.1 Locus of Control and Neoclassical Choice

The expected profit maximization and expected utility maximization problems are workhorses of neoclassical choice theory. In order to be incorporated into neoclassical choice theory, locus of control must influence a subjective element present in the conditions that characterize the solutions to these problems. In this section, I show that this means affecting preferences, probabilities, or production functions.

Let output result from two aggregate inputs (x,e), where x is an input under the decision-maker's control and e is an input controlled externally. For consistency with the proposed set of economic activities in which locus of control is relevant, assume that e is imperfectly observable. While the external input is not necessarily generated by a stochastic process, assume that the decision-maker assigns some probability to each possible realization of e and that these probabilities can be represented by the probability density function $\phi_i(e)$. Given an input cost (c), output price (p) and wealth endowment (A_i), the expected profit and utility maximization problems can be written as:

$$\max_x E[\pi_i] = \int_e (pf_i(x,e) - cx)\,\phi_i(e)de \quad s.t. \quad x \geq 0,\ cx \leq A_i \tag{1}$$

$$\max_x E[U_i] = \int_e U_i\,(pf_i(x,e) + A_i - cx)\,\phi_i(e)de \quad s.t. \quad x \geq 0,\ cx \leq A_i \tag{2}$$

To differentiate locus of control from the colloquially similar notion of perceived self-efficacy, I will assume that x can be precisely chosen[2]. This results expectations being written as a single integral over e in Equations 1 and 2. The subscript i is used to identify components of the optimization problems which might differ across individuals due to economic position or subjective beliefs. These items will be the primary candidates through which locus of control might influence decision-making.

The conditions for interior solutions to each problem are given by:

$$p\int_e \left(\frac{\partial f_i(x,e)}{\partial x}\right)\phi_i(e)de = c \tag{3}$$

$$p\int_e \left(U_i'(pf_i(x,e) + A_i - cx)\frac{\partial f(x,e)}{\partial x}\right)\phi_i(e)de = c\int_e \left(U_i'(pf_i(x,e) + A_i - cx)\right)\phi_i(e)de \tag{4}$$

[2]Perceived self-efficacy deals with a decision-maker's belief that, given a desired course of action, she can successfully execute that course of action. See Wuepper and Lybbert (2017) for more details.

The maximization programs and the equations that characterize their solutions highlight various ways that behavioral influences might affect neoclassical choice. In Equations 1 and 2, both probability distributions and production functions could be influenced subjectively. In addition, differences in the constraint set, here represented only by the individual-specific endowment (A_i) can result in changes to the optimization program. Equations 3 and 4 highlight the role of beliefs about the expected marginal returns to investment as the solution moves away from constraint boundaries.

The same intuition holds for a discrete choice across technologies, which most closely resembles the empirical application that will follow. Consider the choice between technologies f^1 and f^0 facing the profit maximizing decision-maker i. Assume that both technologies produce the same type of output. Evaluating each at her optimal input choice, decision-maker i will choose technology f^1 over f^0 if the value of the additional production exceeds the cost differential. Instead of the slope of a continuous production function as in Equation 3, the marginal product of investment is now defined on the discrete jump in production across technologies.

$$p \int_e \left(f_i^1(x^1, e) - f_i^0(x^0, e)\right) \phi_i(e) de > (c^1 - c^0)x \tag{5}$$

Equation 5 contains the same subjective elements as the earlier formulations. Below, I briefly consider each subjective element and its relation to or distinction from locus of control. The section concludes by summarizing the testable implications of this exercise.

2.1.1 The Subjective Production Function

Locus of control has thus far been presented as a belief about the input output relationship. For general locus of control, the concept of "output" is fairly abstract. As we focus attention toward more activity specific locus of control, the idea of output becomes clearer. An intuitive understanding of locus of control as a balance between the influence of inputs controlled by the decision-maker and external forces comes into focus. Taken to the extreme specificity of a particular production function, we encounter something like the familiar economic concept of marginal product.

The marginal products that underpin the conditions in Equations 3 and 4, however, do not capture the balance of forces that define locus of control. It would also be incorrect to define locus of control in an activity as a ratio of marginal products, which except in extreme cases is not constant across levels of x and e. Defining locus of control in an activity as the expected ratio of marginal products also fails to solve the problem, as it begins to conflate subjective probabilities with beliefs about the input-output relationship.

Rather than define locus of control – either general or activity specific – using the production function, I will hypothesize that locus of control affects beliefs about the production function in a predictable way. The most likely hypothesis is that a decision-maker's locus of control affects her beliefs about the marginal product of inputs under her control and those controlled by external factors.

Call LOC_i the locus of control for individual i. Keeping with convention, higher values of LOC_i are associated with a more external locus of control. Continuing with the two input example, an individual's belief about the marginal product of x and e are given by $f_{x,i}$ and $f_{e,i}$ respectively. We could then write an individual's beliefs about the marginal products as functions of, among other factors, her locus of control. Across an otherwise similar population we then might expect that, on average, individuals with more external locus of control believe that the return to externally controlled inputs is larger and that the return to internally controlled inputs is smaller.

$$\frac{\partial E[f_x|LOC_i]}{\partial LOC_i} < 0 \tag{6}$$

$$\frac{\partial E[f_e|LOC_i]}{\partial LOC_i} > 0 \tag{7}$$

Note that this expectation is across a population of decision-makers not over the distribution of external forces. In later sections I will show that this relationship exists in the data and is not a mechanical function of the activity specific locus of control instrument.

2.1.2 The Subjective Probability Distribution of the External Input

The next subjective component of the decision criteria concerns the probability distribution of the externally controlled input captured by $\phi_i(e)$. A pessimistic belief that e is always very low will clearly affect optimal investment in Equations 3 and 4. This is most easily demonstrated in Equation 3 where the right-hand side is constant the left-hand side is a function of e and its probability distribution. If the marginal product of x is increasing in e and $f(x, e)$ exhibits diminishing marginal returns to its arguments, then shifting probability weight to low values of e necessitates a reduction in the optimal choice of x to satisfy Equation 3. An optimistic belief will do have the opposite effect.

Locus of control speaks to the question of whether the decision-maker controls outcomes or whether external forces are the dominant force. In the two input case, the relevant question with respect to the external input is then, "If e goes from its lowest value (e_l) to its highest value (e_h), what will happen to output?" It is not, "How likely is observing the lowest value of e?"

Empirically, across the households in the sample we would expect to see no systematic relationship between the locus of control measures and the expected value (or any other moment) of the the externally controlled input.

2.1.3 The Utility Function

In the expected utility maximization case, it could be suggested that differences in locus of control are reflected in the utility function. A number of contributions to the role of behavioral influences in neoclassical choice have come through this avenue. Using reference dependent utility, for example, Genicot and Ray (2017) allow aspirations to be socially determined and Lybbert and Wydick (2018) develop a framework for incorporating hope and hopelessness into economic models. Rather than change the function itself, Moya (2018) considers the effects on risk attitudes of exposure to violence in Colombia.[3]

Locus of control is not amenable to modeling as a characteristic of utility functions. The distinction comes in once again noting that locus of control speaks to the outcomes resulting from a given set of inputs. It does not influence whether a decision-maker has a preference for one set of outcomes over another. That is not to say, however, that locus of control is not relevant for utility maximization. By influencing beliefs about the production function, locus of control may affect perceptions of production risk. This would have clear have implications for risk averse decision-makers.

As with subjective expectations about the probability distribution of e, we would not expect to see a systematic relationship between utility function parameters and locus of control.

2.1.4 Prices, Endowments, and Other Constraining Elements

The final set of components in the neoclassical choice problem are prices and endowments. We can think of these components as determining the constraint set more broadly. This area has also received recent attention through the behavioral economic lens. Banerjee and Mullainathan (2008) and Mani et al. (2013) consider the cognitive costs and associated constraints of poverty. New work by Alloush (2017) provides empirical estimates of the

[3]This is by no means a complete review, only acknowledgment of a small number of papers contributing to the field and which have influenced my current work.

bi-directional relationship between psychological well-being and poverty. And Laajaj (2017) considers the implications of psychologically engaging with a gloomy future on the choice of time horizon in planning problems.

Locus of control may relate to the constraint set in a number of ways. The maintained hypothesis throughout this discussion is that locus of control reflects exposure to risk. If risk exposure is higher in remote and under-served areas that lack well-functioning markets, there will likely be empirical regularities between locus of control and prices. Similarly, if risk-exposed areas are also poor, endowments will likely be low among populations with an external locus of control.

It is also not possible to definitively say that changing endowments or prices should have no effect on locus of control. If increasing endowments opens up the choice set to include more options that the decision-maker believes increase her ability to affect the production process relative to forces outside of her control, locus of control could move internally as a result. The same may be true of market access and the resulting input and output prices. Any relationship, however, should be one-directional. Locus of control should have no effect on prices or endowments.

2.2 Testable Implications

The following testable implications emerge from consideration of the history of locus of control in psychology and its intuitive connection to neoclassical models of choice behavior.

Implication 1. *Activity specific and general locus of control can be elicited separately.*

Implication 2. *The newer an activity is, the strong the influence of locus of control is likely to be. General locus of conrol will play a larger role in newer activities.*

Implication 3. *Among the elements characterizing the solution to neoclassical choice problems, the most likely place for locus of control to exert an influence is on subjective beliefs about the production function.*

Implication 4. *No relationship should be observed between locus of control and the probability distribution of externally controlled inputs or risk attitudes.*

Implication 5. *If exposure to risk is associated with market access or economic circumstance, there may be meaningful relationships between locus of control, prices, and endowments.*

I now turn to the case of rainfed maize production in Eastern Africa as both an example of the environment in which locus of control is relevant for understanding technology adoption in the face of risk and as a test of the implications presented above.

3 Rainfed Maize Production in Eastern Africa

As of the turn of the century, forty-percent of total agricultural production in developing countries was rainfed. That share is higher, nearly sixty-percent, for cereals, which provide food and economic security for many smallholding farm households (FAO, 2002). The quality of a growing season faced by these households is a perfect example of the kind of external input described in the previous section. Growing season quality is a complicated interaction of rainfall, temperature, and timing, all of which interact with agroecological conditions that may be unknown to farmers. Not only do these factors act themselves as an input in production, but they combine to influence, or even overwhelm, the influence of inputs controlled by the farmer.

While staple crops remain a dominant source of calories for poor households worldwide, that role is particularly strong in the maize-producing countries of Eastern Africa. According to FAO estimates, households in the region derive nearly sixty percent of calories from cereals, roots, and tubers. In some countries this number is significantly higher. Households in Mozambique, for example, are estimated to derive over seventy percent of calories from staple foods (FAOSTAT, 2017). Those who rely on this level of staple consumption are highly exposed to fluctuations in the production and prices of the commodities on which their economic and food security are based. This vulnerability is born out in high rates of undernourishment, stunting in children under five years old, and anemia in pregnant women (FAO, 2015), all of which have severe consequences for the physical and cognitive development of children as well as the economic opportunities of households (Hoddinott and Kinsey, 2001; Alderman et al., 2006).

Agricultural innovations that improve the yields and resilience of staple crops hope to lessen the impacts of weather shocks and, subsequently, shocks to nutrition and income. In 2015, researchers from the University of California, Davis and the International Center for the Improvement of Maize and Wheat (CIMMYT) began a randomized control trial on the impact of drought-tolerant (DT) maize seed and index-based agricultural insurance on the welfare of small farm households. Parallel projects were launched in the countries of Mozambique and Tanzania. In each country, the research team worked with local seed and insurance companies to promote the new technologies.

As part of the study, yearly surveys are carried out with just over 3,000 households across 153 communities. Study participants were randomly selected from rosters of all maize growing households in their respective communities. While the principle results of this paper do not draw directly on the randomized experiment, the yearly surveys conducted starting in 2016 offer an opportunity to collect detailed data on agricultural behavior and beliefs from a population of maize producers likely to have experienced diverse shocks that could influence their locus of control.

Tables 1 - 3 summarize the sample from the two countries with respect to their economic position, portfolio of income generating activities, and food security status. While all households in the study grow maize, they differ significantly in their other activities as well as in their economic position. Most households are engaged in a number of activities to generate income, including wage labor and operating businesses. A significant fraction of households however, thirty-seven percent in Tanzania and thirty-four percent in Mozambique, report having no source of income other than maize production.

Table 1: Summary of Household Characteristics and Asset Ownership

	Tanzania	Mozambique
Average HH Members	6	6.9
Highest Level of Education (HH Head)		
None or Below Lower Primary	.18	.39
Lower Primary	.08	.36
Upper Primary	.67	.15
Secondary or Above	.07	.10
Average Simple Poverty Score$^+$	37.4	25.7
Probability Below National Poverty Line	20.2	72
Probability Below International $1.25/Day Line	35.2	78.3
Asset Ownership		
Mobile Phone	.80	.56
Bicycle	.53	.76
Radio	.60	.57
Solar Panel	.37	.45

$^+$ (Schreiner, 2012; Schreiner and Lory, 2013). Tanzania probabilities are upper bounds as one question necessary to calculate the full SPS Score is missing.

Table 2: Agricultural Activities and Income Generation

	Tanzania	Mozambique
Maize Production and Practices		
Area Planted (ha)	1.7	2.7
Use Improved Seed	0.59	0.46
Use Chemical Fertilizer	0.02	0.03
Crop Portfolio		
Grow Staples	.79	.79
Grow Cash Crops	.68	.67
Income Generating Activities		
Maize Only	.37	.34
Salaried Job	.04	.16
Operate A Business	.39	.34
Labor For Wages	.29	.32
Receive Pension	.02	.05
Receive Remittances	.11	.17

Table 3: Food Security and Credit Access

	Tanzania	Mozambique
Fraction of Households That:		
Experienced Food Insecurity In Past Year	.37	.78
Had to Rely on Less Preferred Foods	.28	.63
Limited Variety of Meals	.13	.50
Reduced Meal Size	.26	.62
Had No Food in the House	.13	.41
Went Without Food for 24 Hours	.06	.44
Fraction of Households That:		
Have Access to Formal Credit	.05	.03
Have Access to Formal Savings	.09	.05
Could Get a Small, Informal Loan[++]	.79	.43
Could Get a Medium, Informal Loan	.48	.22
Could Get a Large, Informal Loan	.31	.08

[++] Small = USD 5, Medium = USD 25, Large = USD 100

In terms of agriculture, most households grow a combination of staple crops and cash crops in addition to maize. Maize, however, remains central to households' economic and food security. The average household cultivates between one and three hectares of maize and plants predominantly local, non-certified seed varieties. Relying so heavily on rainfed agriculture makes households vulnerable to suffering food and economic insecurity during years characterized by drought or flood.

Table 3 shows just how vulnerable this sample of households is. Nearly forty-percent of households in Tanzania suffered a food insecure even in the year prior to the first round of surveys. This number was almost eighty-percent in Mozambique, which is both poorer and suffered broadly from a severe drought in the year prior to the beginning of the project. The lower half of the table, showing access to formal credit and savings, highlights another dimension of why weather fluctuations so quickly turn into food insecure events for these households. Less than ten percent of households in the study have access to formal credit or savings products. While most claim they could access a small informal loan (less than USD 5), this number drops off quickly when asked about slightly larger values. What's more, these informal networks have difficulty dealing with large covariate shocks such as drought.

As discussed in Section 2, longterm exposure to such a risky environment may result in an external locus of control. The next section lays out the instruments used to measure locus of control before turning to its influence on the adoption decision.

3.1 Eliciting Locus of Control

Locus of control can range from fully general (how the world works) to highly specific (maize production in a rainfed environment). General locus of control is often easier to elicit, though it may provide only weak predictions of behavior in specific activities. While the psychology literature is careful to acknowledge the existence of multiple locus of control domains (Rotter, 1975; Lefcourt et al., 1979), the application of locus of control to economics has been less thorough in doing so. I collect data that allows for the elicitation of both fully general and maize-specific measures of locus of control. This allows me to better understand the relationship between the two and trace their influences on investment behavior in agriculture.

3.1.1 General Locus of Control: The Levenson IPC Scales

Survey instruments to elicit general locus of control typically rely on a series of questions asking respondents to identify with a framing consistent with either own control of outcomes or external control of outcomes. This can be achieved using either Likert scales or forced choice pairs. Both elicitation methods result in ordinal scores and are best used to situate respondents with respect to a comparable population.

Unlike some psychological instruments, there is not a clear threshold that differentiates internal agents from external agents. For example, a score above ten on CESD-R depression scales indicates a high probability of suffering from depression (Alloush, 2017). No such sharp threshold exists for locus of control. Imposing such an interpretation was cited as one of the most frequent misuses of locus of control in the psychology literature (Rotter, 1975). Instead, a decision-maker's position in the distribution of survey responses identifies them as holding more external or more internal beliefs than their peers.

The general locus of control measure administered as part of the yearly survey is a version of the Levenson IPC scales (Levenson, 1981), adapted for local appropriateness and language needs. The Levenson scales seek to capture attribution of control to each of three sources. The internal dimension (I) reflects control by one's own actions. Control of outcomes can also reside with chance influences (C) or powerful other agents (P) such as community leaders, politicians, spouses, or other figures of power. The latter two dimensions are both external in the classical Rotter sense.

Of twenty-one total statements, seven belong to each of the three scale dimensions[4]. To address well-known measurement challenges (Soto et al., 2008; Macours and Laajaj, 2017; Rammstedt et al., 2013), I correct for acquiescence bias (following Rammstedt et al. (2013)) and create an general locus of control index using a factor analysis process. Factor analysis is particularly well suited for this application as each of the Likert scale items is essentially a proxy for an underlying latent variable representing a respondent's locus of control. Factor analysis allows us to learn about this latent variable and reduce the dimensionality of the data significantly. I describe the process in more detail in Appendix 7.1.

Table 4 and Figure 1 summarize the distribution of the general locus of control index. By construction, the distribution for the full sample is centered on zero. In addition to the standard deviation of the index, I also report the mean index value for each tercile of the distribution. Because the primary purpose of the Levenson scales are to create ordinal rankings of respondents, the raw index value is difficult to interpret. We can confidently say, however, that respondents in the upper (third) tercile exhibit significantly more external locus of control than those respondents in the lower tercile. For this reason, many of the behavioral regression specifications will use indicators for a household's tercile position in locus of control distribution rather than the raw index value. Movement across terciles, it

[4]There are twenty-four elements in the standard Levenson IPC instrument. I drop three, one in each dimension, for issues of cultural relevance.

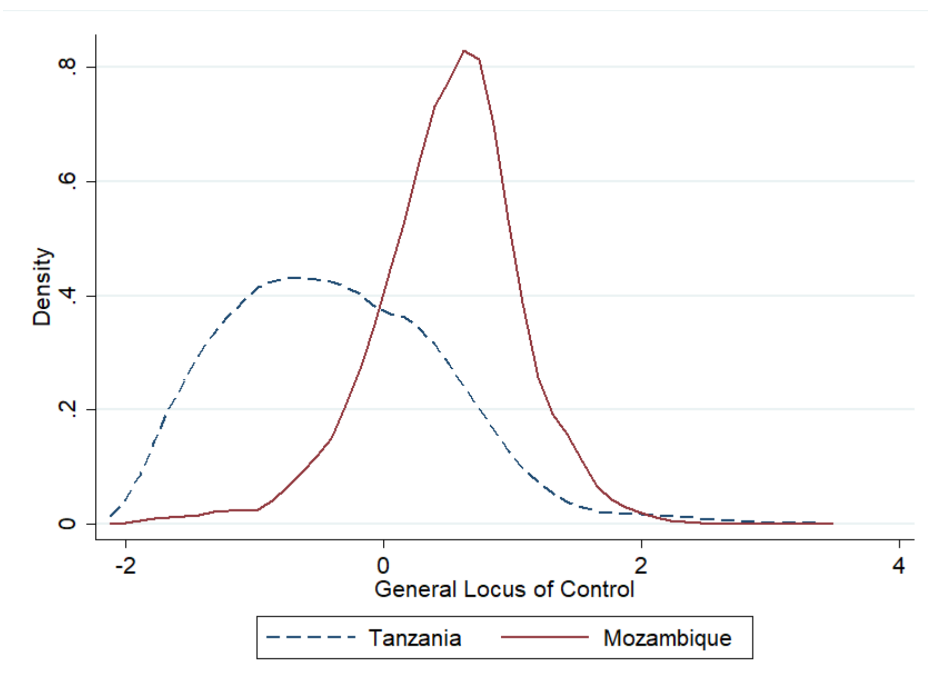
can be noted, is equivalent to just over a one standard deviation change in the index value.

There are many reasons to collect data on general locus of control. As discussed in the review of both economic and psychology literature, general locus of control has been shown to correlate with a number of activities and decisions. As a standard component of broad surveys, then, it may be a useful and low-cost inclusion. It's inclusion here shows that, on average, households in Mozambique display more external locus of control than do their counterparts in Tanzania. This can be hypothesized to both result from the different shocks to which they have been exposed and to influence their behavior moving forward. To best understand decision-maker beliefs about specific domains, however, a more activity specific locus of control measure is needed.

Table 4: General Locus of Control Distribution

		$LOC_{General}$		
	σ	Tercile 1	Tercile 2	Tercile 3
Full Sample	0.85	-0.99	0.09	0.90
Tanzania	0.84	-1.26	-0.43	0.58
Mozambique	0.56	-0.11	0.53	1.06

Figure 1: General Locus of Control Distributions in Mozambique and Tanzania



3.1.2 Maize-Specific Locus of Control

An effective instrument for maize-specific locus of control will capture the extent to which a decision-maker believes that variation in maize harvest is attributable to her actions relative to forces outside of her control. In addition to capturing the source of variation, the measure must not be sensitive to the scale of farming operations. This will allow for comparisons among farmers with plots of various sizes.

In order to create such a measure, survey enumerators have the following conversation with each farmer. First, a reference point is created by asking the area of a farmer's best maize plot and the quantity of maize seed typically planted on this plot. The respondent is then asked to imagine that she plants her plot with a specific input bundle. Three input bundles are presented: local seed varieties[5] with no fertilizer, improved seed varieties with no fertilizer, and improved seed varieties with fertilizer. For each input bundle, the respondent is asked how much maize she would expect to harvest under "poor", "normal", and "very good" rain conditions. The top panel of Figure 2 shows the map resulting from this activity.

The farmer's belief in her own ability to influence harvest outcomes ($Maize_I$) is conceptualized as follows. For a given weather state, how much does her choice of input bundle affect harvest outcomes? The intuition is identical for farmer beliefs about the influence of external forces ($Maize_E$) on production outcomes. Now, however, the input bundle is constant and variation in harvest comes from moving across weather states. Figure 2 illustrates.

To capture the balance between internal and external influence that characterizes locus of control, I create a ratio of the two beliefs described above. Let the three input bundles presented to the respondent be given by $j \in \{1, 2, 3\}$ and the three states of weather be given by $k \in \{l, n, g\}$ (low, normal, good). Let y_{jk} be the harvest expected from using input bundle j in weather state k. Maize-specific locus of control is defined as:

$$LOC_{Maize} = \frac{Maize_E}{Maize_I} = \frac{\sum_j \left(\frac{S_{j\bullet}}{\bar{y}_{j\bullet}}\right)}{\sum_k \left(\frac{S_{\bullet k}}{\bar{y}_{\bullet k}}\right)} \tag{8}$$

Where

$$S_{j\bullet} = \sqrt{\frac{\sum_k (y_{jk} - \bar{y}_{j\bullet})^2}{2}} \tag{9}$$

[5]Local seed varieties refer to non-certified, saved seeds. Often, local maize seed is simply maize grain planted as seed. Improved seed varieties refer to certified maize seed. Both hybrid and open-pollinated varieties are considered improved maize seed.

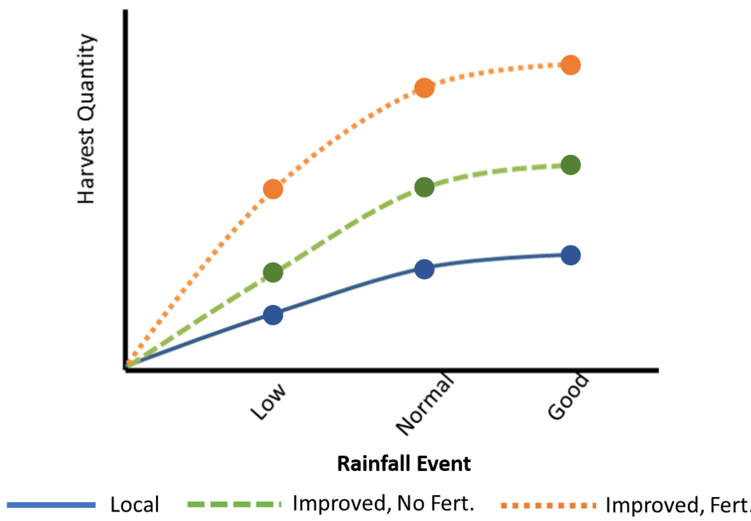
$$S_{\bullet k} = \sqrt{\frac{\sum_j (y_{jk} - \bar{y}_{\bullet k})^2}{2}} \tag{10}$$

$$\bar{y}_{j\bullet} = \frac{1}{3}(y_{jl} + y_{jn} + y_{jg}) \tag{11}$$

$$\bar{y}_{\bullet k} = \frac{1}{3}(y_{1k} + y_{2k} + y_{3k}) \tag{12}$$

Consistent with the conventions from psychology, larger numbers indicate more external locus of control – the belief that weather plays a more significant role in the variability of production outcomes relative to the choice of input bundle. Figure 3 shows how the hypothetical harvest activity differs for households demonstrating an internal and external locus of control in maize production. The left-hand panel of Figure 3 contains data from a farmer scoring in the most internal tercile of the maize-specific locus of control measure. Relative to the vertical travel of each input line, significant variation is visible across lines. Contrast this with the right-hand panel, which contains data from a farmer scoring in the most external tercile of the measure. Here, the vertical travel of each input line clearly dominates the variation in output across lines.

Figure 2: Locus of Control in Maize Production: Harvest Under Various Weather-Input Combinations



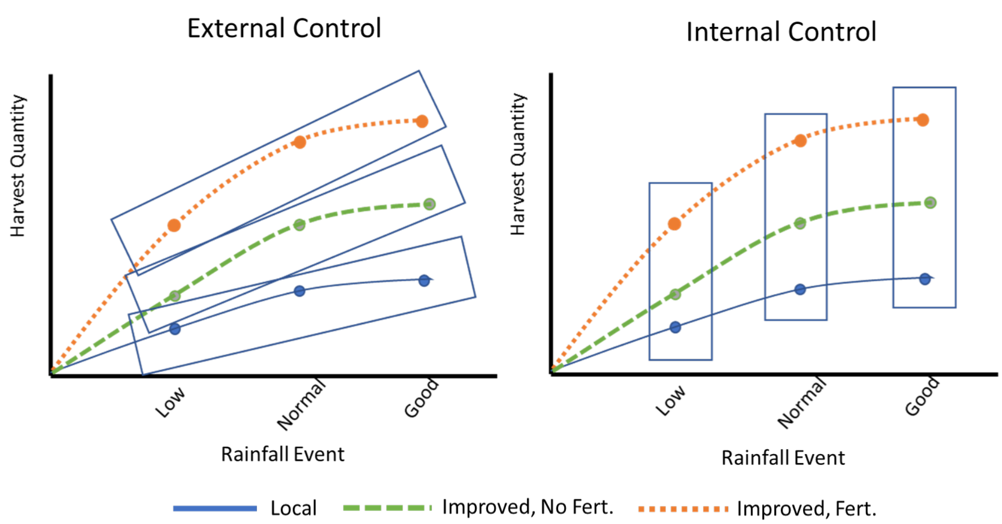
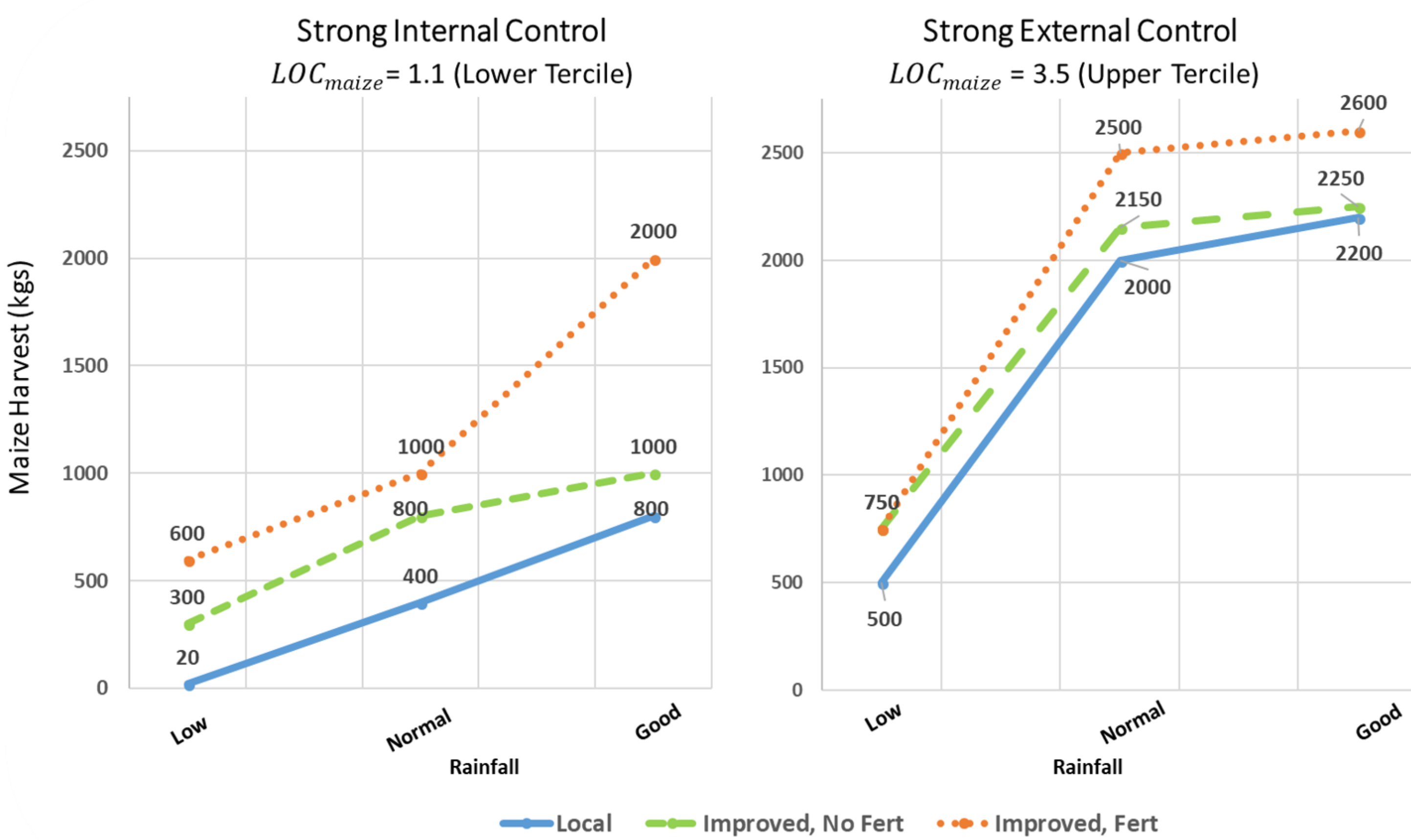


Figure 3: Locus of Control in Maize Production: Empirical Examples



On average, households in the Mozambican demonstrate more external locus of control in maize production than do their Tanzanian counterparts. Figure 4 compares density plots of the maize-specific locus of control measure across the two countries. A horizontal line has been placed at the value of one, indicating equal balance between the influence of input choice and weather on variation in production outcomes.

Figure 4: Maize-specific Locus of Control: Mozambique and Tanzania

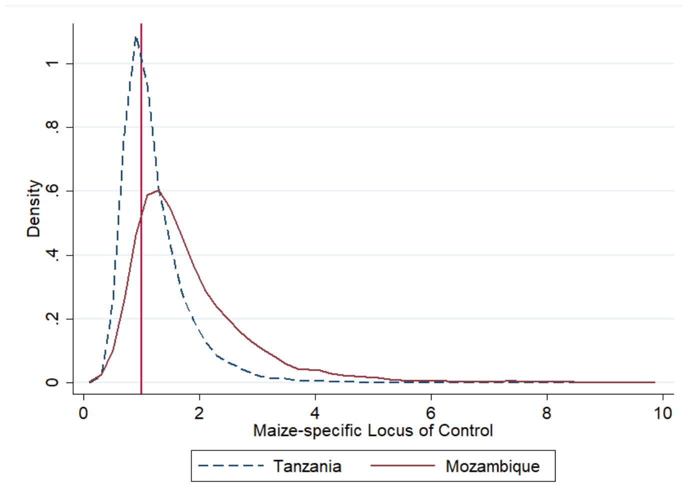


Table 5 summarizes these distributions further. As with the general locus of control measure, I also report the mean locus of control measure for households in each tercile of the distribution.

Table 5: Distributions of Maize-Specific Locus of Control by Country

	LOC_{Maize}				
	Mean	SD	Tercile 1	Tercile 2	Tercile 3
Full Sample	1.49	1.04	0.80	1.24	2.44
Tanzania	1.24	0.61	0.76	1.11	1.85
Mozambique	2.01	1.43	1.01	1.67	3.33

4 Locus of Control and Adoption of Improved Maize Seed

Section 2 provides a number of predictions about how locus of control might affect a farmer's decision to adopt improved seed varieties, as well as how locus of control might relate to other components of the decision-making problem. With instruments for both maize-specific and general locus of control now in hand, I turn to testing some of those predictions.

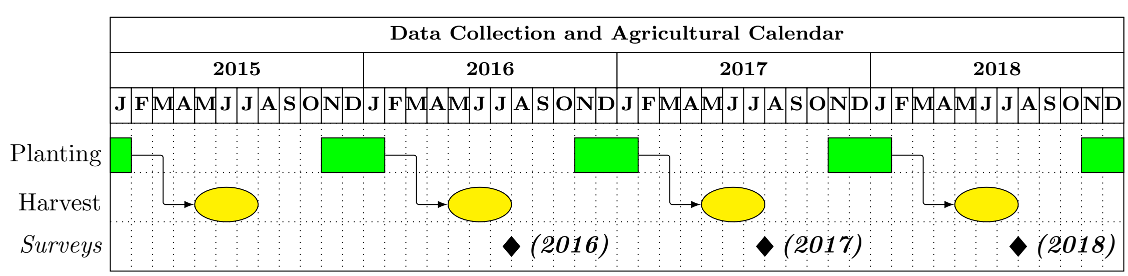
The first task is to establish whether or not locus of control predicts improved seed use. Across the three rounds of data collected from 2016 to 2018, 62% of households in Tanzania and 35% of households in Mozambique reported using an improved seed variety. I begin by treating this data as observational, estimating linear probability models of the form described in Equation 13. The decision to adopt improved maize varieties is regressed on measures of both maize-specific and general locus of control. With no prior reason to suspect that the conditional expectation function follows a particular non-linear functional form, linear probability models provide a good approximation of the conditional expectation function and facilitate comparison of marginal effects across models (Angrist and Pischke, 2008). I use robust standard errors in all specifications, due to the inherent heteroskedasticity of the linear probability model.

$$Pr(y_{i,t} = 1) = \alpha + \beta_1' LOC_{Maize,it-1} + \beta_2' LOC_{General,it-1} + \gamma' Z_{it-1} + \epsilon_{it} \tag{13}$$

In order to hone in the beliefs most relevant to decision-making, I make use of the panel nature of the data. I use lagged beliefs to avoid simultaneity and recall bias. Farmers who were unhappy with the year's outcome might under-report input usage. At the very least, a farmer's experience using (or not using) improved seed varieties in the current year would already be reflected in their beliefs about the extent to which their choices and external forces affected harvest outcomes.

Figure 5 depicts the timing of survey rounds and the agricultural calender. To make the chain of events clear, focus briefly on the 2016 survey round. The beliefs elicited at this time reflect the agricultural season and harvest that just concluded in June and July. These beliefs are the most relevant with which to predict behavior at the start of the 2017 agricultural season in November and December.

Figure 5: Timeline of Survey Enumeration and Agricultural Decision-making



The model pools observations from both countries, with data on improved maize use coming from the 2017 and 2018 survey rounds. To account for differences in use rates across countries and years, I include an indicator equal to one if the observation is from the 2018 survey round and another equal to one if the observation is from Mozambique (in specifications without community fixed effects).

Table 6 contains baseline evidence that locus of control is related to the decision to adopt improved maize varieties. In this first specification, a farmer's adoption decision is regressed on her maize-specific and general locus of control measures with no additional controls aside from community fixed effects. Subsequent models will add controls for other common determinants of adoption and controls for other subjective elements of the neoclassical choice problems described earlier. This will provide insight into the hypothesized mechanisms.

The first two columns predict adoption using a household's tercile position in the general and maize-specific locus of control distribution. As noted above, the raw scores – used in columns three and four – are difficult to interpret. Models two and four add village fixed effects to account for issues of market access, agroecological factors, and historical weather patterns.

Across all four columns, a more external locus of control is associated with a reduced probability of adopting improved maize varieties. These results are particularly strong for the maize-specific locus of control measure. Being located in the upper, most external tercile of maize-specific locus of control is associated with an economically meaningful and statistically significant drop in the probability of adopting improved maize seed varieties of eleven percent.

The effect of an external locus of control in maize production reduces to a more moderate but still significant 3.8 % when village fixed effects are introduced. The maize-specific locus of control measure created in Section 3.1.2 embodies many experiences and characteristics of the production environment, among them agroecological conditions and soil quality. Village fixed effects seek to remove the influence of localized access problems, however they may also remove some influences most correctly attributed to maize-specific locus of control.

Table 6: Impacts of Locus of Control on the Adoption of Improved Maize Varieties

	Report Using an Improved Maize Variety			
	(1)	(2)	(3)	(4)
Maize-specific LOC				
Tercile 2	-0.0841***	-0.0284**		
	(0.0164)	(0.0126)		
Tercile 3	-0.112***	-0.0382**		
	(0.0187)	(0.0143)		
LOC_{Maize}			-0.0200**	-0.00300
			(0.00883)	(0.00605)
General LOC				
Tercile 2	-0.0543***	-0.0232*		
	(0.0197)	(0.0136)		
Tercile 3	-0.0857***	-0.0349**		
	(0.0223)	(0.0169)		
$LOC_{General}$			-0.0552***	-0.0251***
			(0.0103)	(0.00730)
Mozambique	-0.0682		-0.0778*	
	(0.0408)		(0.0433)	
2018	-0.0417**	-0.0457***	-0.0401**	-0.0448***
	(0.0161)	(0.0161)	(0.0162)	(0.0161)
Constant	0.679***	0.583***	0.601***	0.546***
	(0.0333)	(0.0129)	(0.0314)	(0.0106)
Control Set	No	No	No	No
Village FE	No	Yes	No	Yes
Observations	5398	5398	5398	5398
R^2	0.033	0.276	0.029	0.275

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.1 Locus of Control on Subjective Probabilities

The role of e in Section 3 is played by the quality of a growing season, and more specifically, the quality of rainfall for maize production. To gauge farmer's expectations about the distribution of rainfall events, each respondent is asked a series of questions. First, a farmer is asked how many years out of ten she expects to have normal rainfall for growing maize. She is then asked, out of the remaining years, how many years she expects to have very good and very bad rainfall for producing maize.

In both countries, the average household expects good rain three out of ten years and poor rain two out of ten years. Table 7 shows that these responses are only weakly correlated to locus of control.

Table 7: Correlation Among Locus of Control Measures and Rainfall Expectations (Years out of ten)

	Tanzania		Mozambique	
	$LOC_{General}$	LOC_{Maize}	$LOC_{General}$	LOC_{Maize}
Rain = Bad	0.07	-0.02	-0.03	0.02
Rain = Normal	-0.03	0.05	-0.01	0.03
Rain = Good	-0.03	-0.04	0.04	-0.05

4.2 Impact of Locus of Control on Risk Attitudes

While the full household survey does not include a module to estimate risk aversion coefficients, I conducted an auxiliary survey with a subset of study participants in Mozambique to better understand the properties of the various measures of locus of control. This auxiliary survey was conducted with just under 200 randomly selected participants in 10 communities.

As part of the auxiliary survey, participants completed an incentivized module to elicit the prospect theory parameters associated with curvature of the value function and probability weighting. The survey also contained a set of four questions concerning "general risk attitudes", which capture decision-makers' feelings toward new ideas, technologies, and trying new things. This risk attitudes module is part of the full household survey and serves to link the auxiliary results to the full sample results.

No strong correlations are visible between either curvature of the value function (Sigma) or weighting of small probabilities (Alpha) and locus of control in maize production, strengthening the case that risk aversion and locus of control are separate concepts. A stronger

Table 8: Locus of Control and Risk Attitudes Among a Mozambican Sub-population

	LOC_{Maize}	Risk Index	Sigma	Alpha
Risk Index	0.11	1.00		
Sigma	0.04	0.04	1.00	
Alpha	0.03	0.03	0.37	1.00

positive correlation is visible between the general risk index and locus of control in maize production. Higher scores in the risk index are associated with an increased willingness to engage with new ideas and experiences. This variable exists in the full dataset as well and will be included as a control variable below.

4.3 Re-estimating the Impact of Locus of Control on Adoption

I now re-estimate Equation 13 this time including controls for beliefs about the probability of weather events and risk attitudes, as well as a set of controls for common determinants of adoption. The complete control set includes a proxy for household economic status, scale of farm activity, education, and recent shocks to agriculture[6]. Like locus of control, the set of controls are lagged to best fit into the decision-making timeline. Table 9 contains the resulting estimates[7]. The additional controls have little impact on the fit of the model. The impact of general locus of control reduces somewhat, but little impact is seen on the activity specific measure. This is consistent with the lack of relation shown in the previous two sections.

4.4 Impacts of Locus of Control on Subjective Returns to Investment

The primary avenue through which locus of control is hypothesized to affect investment decisions is by affecting the subjective production function. While the current data are not sufficient to estimate the production function itself, I can construct a measure of the perceived returns to adopting improved maize varieties similar to the condition laid out in Equation 5 (reproduced below).

[6]I use satellite-measured rainfall data matched to household location to include an indicator equal to one if the household experienced sub-optimal rainfall the previous season. Optimal rainfall for maize is between 500-800 millimeters. The indicator variable constructed here takes a value of one if cumulative rainfall for the 120 days following planting is less than 400 millimeters.

[7]The full table with covariates can be found in Appendix 7.6

Table 9: Impacts of Locus of Control on the Adoption of Improved Maize Varieties

	Report Using an Improved Maize Variety			
	(1)	(2)	(3)	(4)
Maize-specific LOC				
Tercile 2	-0.0772***	-0.0267**		
	(0.0150)	(0.0126)		
Tercile 3	-0.108***	-0.0361**		
	(0.0179)	(0.0145)		
LOC_{Maize}			-0.0207**	-0.00316
			(0.00869)	(0.00589)
General LOC				
Tercile 2	-0.0380*	-0.0144		
	(0.0195)	(0.0138)		
Tercile 3	-0.0589***	-0.0186		
	(0.0215)	(0.0172)		
$LOC_{General}$			-0.0383***	-0.0149*
			(0.00987)	(0.00755)
Controls				
Mozambique	-0.0525		-0.0657	
	(0.0432)		(0.0457)	
2018	-0.0368**	-0.0458***	-0.0362**	-0.0454***
	(0.0161)	(0.0161)	(0.0161)	(0.0161)
Constant	0.388***	0.393***	0.334***	0.368***
	(0.0654)	(0.0453)	(0.0627)	(0.0416)
Control Set	Yes	Yes	Yes	Yes
Strata FE	No	Yes	No	Yes
Observations	5355	5355	5355	5355
R^2	0.050	0.282	0.045	0.282

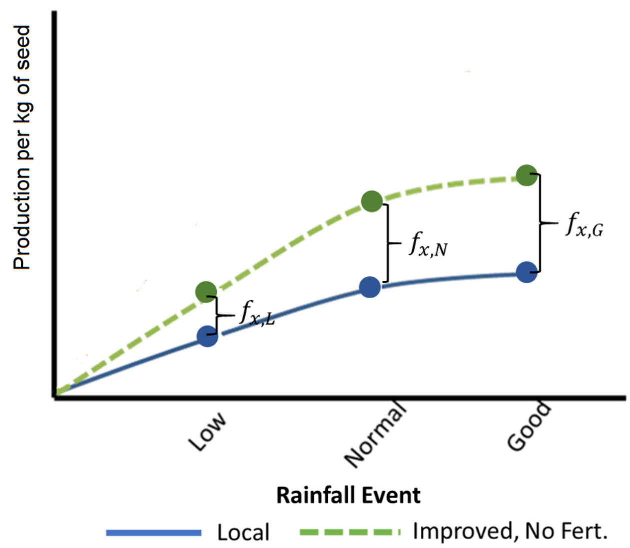
Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

$$p\int_e \left(f_i^1(x^1,e) - f_i^0(x^0,e)\right)\phi_i(e)de > (c^1 - c^0)x$$

Specifically, I can use data from the hypothetical harvest activity to identify the discrete jump in harvest that a farmer expects to follow adoption in each weather state. Figure 6 illustrates. For comparability across farmers, the vertical axis now depicts maize grain harvest per kilogram of maize seed used.[8]

Figure 6: Estimating Expected Marginal Harvest Returns to Adopting Improved Seeds



Despite being constructed with the same data, the expected harvest gain and maize-specific locus of control measure are conceptually and empirically distinct. Appendix 7.2 proves the distinction. In summary, I show that locus of control is invariant to scaling all outcomes by a positive constant, while expected return is not. In the other direction, expected harvest is invariant to adding a positive constant to all outcomes, while this preserves the maize-specific locus of control measure only as a special case.

In order to show that they also distinct in the data, we would like to see that there is sufficient variation in the expected return to adoption across at each point in the locus of control distribution. Figures 13 and 14 (In Appendix 7.2) plot the expected return across terciles and deciles of the maize specific locus of control distribution. A relationship is visible between average expected returns and maize-specific locus of control but substantial

[8]Seed use rates are more reliable than maize-area. The vertical axis could also be constructed using area yields.

variation is also visible at each point in the distribution.

I combine the three yield returns with subjective expectations about the probability of each rainfall state to obtain the expected return on yields of improved maize adoption. Multiplying this by local, year-specific grain prices provides an estimate of the value marginal product of adoption, depicted on the left-hand side of Equation 5. For the right-hand side, I use a farmer's reported seed quantity and the average price of improved seed varieties for each country and year in the sample. Figures 13 and 14 have horizontal lines depicting the expected increase in harvest necessary for adoption to be profitable. At all points in the maize-specific locus of control distribution, adoption of improved maize varieties is viewed as profitable for a significant fraction of households.

Having demonstrated that the maize-specific locus of control construct and the expected return to adoption are distinct, I can now quantify the relationship between the two. Note that there is no concern that general locus of control and expected return to adopting improved varieties are identical. To estimate this relationship, I regress the expected return to adoption on both locus of control measures, once again using a farmer's tercile location in the distribution of each measure.

$$E[f_{x,it}] = \alpha + \beta_1' LOC_{maize,it} + \beta_2' LOC_{General,it} + \nu_v + \nu_t + \epsilon_{it} \tag{14}$$

Where ν_v and ν_t are villag eand year fixed effects. Note that both beliefs are now elicited at time t, which allows for use of all three years of data. Table 10 reports these results.

A more external locus of control, as measured by both the maize-specific and general locus of control measures, are associated with decreases in the expected returns from adopting improved maize varieties. The effects are especially large for the maize-specific measure, where being in the second tercile is associated with decrease of seventeen kilograms of harvest per kilogram of improved seed and being in the most external tercile as associated with a drop of nearly twenty-eight kilograms per kilogram of seed.

These results are suggestive evidence that locus of control affects the subjective production function as posited in Section 2.2. In particular, the association between general locus of control and the expected return from adopting improved seed varieties is intriguing. This locus of control measure is not saddled with the same data limitations as the maize-specific measure, in the sense that it does not use the same data as is used to estimate expected returns to adoption. If anything, we would expect general locus of control to be only a weak predictor of beliefs about the returns to improved seed varieties, which represents a familiar technology for much of the sample.

Table 10: Association between Locus of Control and the Expected Harvest Increase Per Kg of Improved Seed Used

	E[Increase]
Maize-specific LOC	
Tercile 2	-17.06***
	(1.739)
Tercile 3	-27.70***
	(1.707)
General LOC	
Tercile 2	-4.434**
	(1.749)
Tercile 3	-6.281***
	(1.704)
Constant	66.13***
	(1.790)
Year FE	Yes
Village FE	Yes
Observations	8376
R^2	0.230

Clustered standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5 More to the Story

Up to this point I have focused exclusively on the connection of locus of control to elements of neoclassical optimization problems. In an application to the adoption of improved maize varieties among smallholding farmers in Eastern Africa, both activity specific and general locus of control have demonstrated clear links to behavior. Associated evidence also supports the hypothesis that locus of control is primarily related to beliefs about the production function.

The psychology literature, however, and the characterization of locus of control as a belief suggest that there is more to the story. First, the influence of locus of control on behavior were posited to depend on the familiarity of the activity in question. This was hypothesized both for the influence of general locus of control on activity specific locus of control and for the influence of activity specific locus of control on behavior.

Second, while beliefs about the production function and profitability drive action in economic models, human decision-makers also respond to other influences. Locus of control, specifically general locus of control, might be related to the extent that decision-makers incorporate the suggestions and desires of powerful other agents – such as community leaders or researchers–into their behavior.

This final section takes a brief look at these hypotheses by making use of adoption of a new agricultural technology in response to a randomized marketing intervention and detailed data on community meeting attendance in Mozambique.

5.1 Heterogeneous Impacts to a Randomized Marketing Intervention

Prior to the start of the 2015/2016 agricultural season, the UC Davis-CIMMYT research team launched an intensive marketing intervention in cooperation with producers of drought-tolerant maize seed in Mozambique and Tanzania. Study communities were matched into strata based on proximity and agroecological characteristics. Communities were then randomly assigned to treatment and control. Treatment communities received targeted marketing efforts from the research team and seed company partners. Control communities did not. Drought-tolerant seed was sold at market prices[9].

To study the effects of locus of control on the adoption of unfamiliar technologies, I estimate heterogeneous adoption impacts for the randomized marketing intervention using locus of control as a moderating variable. I will consider both maize-specific locus of control and general locus of control as potential sources of heterogeneity.

$$Pr(y_{it} = 1) = \alpha + \theta y_{i,t-1} + \beta_0 Treat_i + \beta_1' LOC_{it-1} + \beta_2 Treat_i \cdot LOC_{it-1} + \epsilon_{it} \tag{15}$$

Estimating heterogeneous impacts according to Equation 15 allows me to use the random allocation of treatment to look at differential uptake of the new technology across terciles of locus of control. The coefficients of interest are the vector of interactions between locus of control and treatment status represented by β_2 in Equation 15, with the necessary exclusion restriction being $E[\epsilon_{it}|Treat_i, LOC_{it-1}] = 0$. As treatment status does not vary for a community, this specification does not include community fixed effects. However, the stratified approach to randomization should result in balance across treatment and control communities on relevant unobservable variables like soil quality, weather history, and market access. Strata fixed effects are included and standard errors are clustered at the community level. In order to not impose stricter correlation in the dependent variable than necessary, I use an ANCOVA specification rather than difference-in-difference.

Earlier in this paper, I discussed at length the challenges facing adoption of improved

[9]With randomly allocated discounts to study price responsiveness in Mozambique. It should also be acknowledged that the marketing intervention may have lowered transaction costs, making the seed slightly cheaper than in the absence of the intervention.

maize seed varieties and their prevalence in both countries. Despite their far-from-universal adoption, most farmers are familiar with the technology and many have used it in the past. Drought-tolerant maize varieties, on the other hand, represent a new technology that, while commercially available, was relatively unknown to most farmers prior to the marketing intervention. If locus of control is more salient for new technologies, we will expect to see the moderating variable play a more significant role in the effect of the treatment on adoption of drought-tolerant seed than on improved seed generally.

Table 11 contains the results of using farmers' tercile position in the locus of control distribution to generate heterogeneous impacts. Heterogeneous impacts with the continuous measure can be found in Table 15 in Appendix 7.6. Columns one and three contain the base-case impacts of the marketing intervention on use of improved and drought-tolerant maize seed, while columns two and four contain the heterogeneous specifications.

Consistent with the hypothesis that locus of control is more active in shaping behavior when technologies are newer, the marketing intervention demonstrates heterogeneous returns in the adoption of drought-tolerant maize varieties but not improved varieties more generally. These impacts are most clearly seen using the maize-specific locus of control instrument. Being in the most external tercile of households according to this measure reduces the impact of the marketing treatment by six percent. While being in the more external terciles of general locus of control does generate negative point estimates, they are similar in magnitude to the influence of general locus of control on the earlier improved seed adoption models and are not significant.

Table 11: Heterogeneous Impacts to a Randomized Marketing Intervention

	Use Improved Maize		Use Drought-tolearnt Maize	
	(1)	(2)	(3)	(4)
$y_{i,t-1}$	0.161***	0.163***	0.0644***	0.0653***
	(0.0189)	(0.0183)	(0.0186)	(0.0190)
Treat	0.282***	0.239***	0.390***	0.452***
	(0.0225)	(0.0336)	(0.0167)	(0.0294)
Maize-Specific LOC				
Treat × Tercile 2		0.00402		-0.0477**
		(0.0301)		(0.0233)
Treat × Tercile 3		0.0381		-0.0605**
		(0.0340)		(0.0244)
General LOC				
Treat × Tercile 2		0.0339		-0.0103
		(0.0323)		(0.0262)
Treat × Tercile 3		0.0366		-0.0360
Constant	0.248***	0.318***	0.0432***	0.0346*
	(0.0147)	(0.0274)	(0.0116)	(0.0189)
Saturated	N/A	Yes	N/A	Yes
Strata FE	Yes	Yes	Yes	Yes
Observations	5563	5355	6210	5816
R^2	0.238	0.239	0.223	0.233

Clustered standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.2 Locus of Control on Community Meeting Attendance and Purchases In Mozambique

Focusing specifically on the sample of households from Mozambique provides a final opportunity to study an interesting element of the relationship between locus of control and behavior. Each year the UC Davis research team and it's local partners facilitated community meeting in all treatment communities in Mozambique. At these meetings, educational sessions were conducted in collaboration with the agricultural extension service on planting practices and the characteristics of drought-tolerant seeds. Drought-tolerant seeds were also available for sale.

Households participating in the study received personal invitations to the community meetings. These invitations, distributed by community leaders, contained information on the date and time of the meeting, as well as the prices of the seeds to be sold. Households were also informed that they would receive a randomly chosen discount on the price of seeds purchased at the community meeting. Discounts were randomly chosen by each participant out of a hat at the community meeting (10%,25% or 50%, with probabilities 0.2, 0.6, and 0.2 respectively). All participants at the community meeting drew a discount upon arrival, regardless of whether or not she eventually made a purchase.

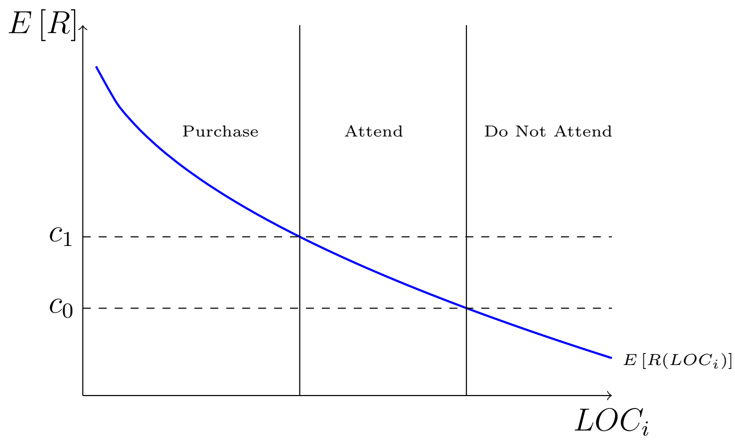
The same story that suggests farmers with a more internal locus of control are more likely to value improved seed varieties above their cost can be made for any cost threshold. Due to the random discount, households do not know exactly what price they will face for improved seed at community meetings. If attending the meeting is costless, all households should attend the meeting and purchase the seed if their randomly drawn discount results in a price below their reservation price. If, instead, there is a significant opportunity cost to meeting attendance, then households with low expected benefits of adoption should not attend. Specifically, households with a valuation less than half the published seed price should not attend.

Figure 7 presents a stylized model of the attendance and adoption decision. I assume that a household's valuation of drought-tolerant seeds decreases as locus of control becomes more external (LOC rises). Two threshold costs are depicted. The first threshold (c_0) represents the opportunity cost of attendance. Household with an expected return lower than the opportunity cost of attendance should not attend. The second threshold represents the total cost of attending and purchasing. Households with an expected return above this level will attend and purchase. Those households with valuations between the thresholds may attend in hopes of receiving a large discount, but generally will not purchase.

Community meetings were held in two years, 2016 and 2017, a few months after the survey rounds in those same years. I regress a household's attendance at the community meeting on her tercile position in the maize-specific and general locus of control distributions, including controls for the survey year. Results are reported in the first column of Table 12. Being in the more external terciles of the maize-specific locus of control distribution are associated with declines of six-and-a-half to seven-and-a-half percent in the likelihood of attending the community meetings.

The second column focuses on the population who attended the community meeting. Here, I regress the purchase decision on locus of control, conditional on attendance. Interestingly, no effects are evident for either locus of control measure. This is also true when the continuous measures are used rather than terciles. This might suggest that the opportunity cost of attendance is large relative to the cost of the seed itself. Once households are present at the meeting, most purchase some quantity of drought-tolerant seed.

Figure 7: Meeting Attendance and Seed Purchases With Opportunity Cost



The community meeting data offers an opportunity to also consider more complicated interactions between locus of control and behavior. Some of these effects may be non-monotonic. For example, if more externally oriented decision-makers are heavily influenced by the suggestions of powerful other agents – such as community leaders, extension agents, or researchers – then they may unlikely to ignore the summons to a community meeting even if they believe there is no return to the seeds being sold.

Figure 8 adds this component to the stylized example, modeled here as an additional benefit (R_{PO}) that comes not from the individual's beliefs about the production process but vicariously through the suggestion of powerful others. I assume that it decreases as the decision-maker's locus of control becomes internal.

Table 12: Community Meeting Attendance and Seed Purchases

	Attend	Purchase|Attend=1
Maize-specific LOC		
Tercile 2	-0.0651**	-0.0297
	(0.0289)	(0.0325)
Tercile 3	-0.0765***	0.0484
	(0.0241)	(0.0360)
General LOC		
Tercile 2	-0.0128	0.00464
	(0.0256)	(0.0324)
Tercile 3	0.0136	-0.0293
	(0.0297)	(0.0345)
2017	-0.237***	-0.0844
	(0.0574)	(0.0583)
Constant	0.696***	0.787***
	(0.0464)	(0.0485)
Observations	1425	756
R^2	0.061	0.015

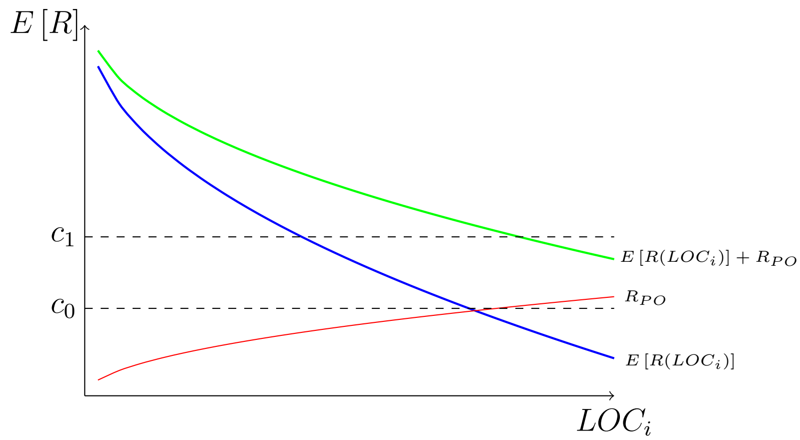
Robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The two mechanisms depicted in Figure 8 can be thought to respond differently to general and activity specific locus of control. Namely, the influence of powerful other agents has no connection to the production function. The data provide some evidence of such a pathway. Table 16 in Appendix 7.6 estimates models for attendance and purchase separately by year. The 2016 results seem to drive the aggregate results. In this year while a more external maize-specific locus of control was negatively associated with attendance, a more external general locus of control was positively associated with attendance.

Whether or not the additional push via the influence of powerful others is beneficial or detrimental depends on where the true returns to adoption lie. First consider the case in which there is a single objective return for all households and it lies above $c1$. In this case, the additional pressure from powerful others induces more individuals to adopt a beneficial technology.

In a different scenario this may not be true. One interesting case is that in which each decision-maker is perfectly informed about the benefit of the technology given their individual circumstance. The true return is then equal to $E[R(LOC_i)]$. In this case, the proper set of decision-makers would already be adopting the technology. The influence of powerful other agents would induce adoption among households for which the true benefit was negative.

Figure 8: Expected Returns and an Influence From Powerful Others



Even in the case where the technology is beneficial to everyone, the most externally oriented households in Figure 8 have been induced to attend the community meeting, incurring the cost c_0, but leave without making a purchase.

The influence of powerful other agents can be likened to "nudges" that have become common topics of discussion among academics and practitioners. The potential negative effect of nudging locus of control towards the internal side of the spectrum highlights the dangers inherent to this practice. If there is such a thing as an optimal locus of control, it would be the locus of control that leads households to have correct beliefs about the production function. The psychology literature noted this early on. Bar-Tal and Bar-Zohar (1977) capture it nicely in a summary of their conclusions about education:

> It should be clearly emphasized that while, on the one hand, it seems desirable to encourage internal perception of locus of control in environments which actually are structured to support self-directive, self-initiative, and self-evaluative behavior; on the other hand, educators should avoid the encouragement of internal perceptions in restrictive and controlling environments. In the latter case, internal perceptions may induce unrealistic expectations because of the existing gap between perceptions of options and the reality, the lack of available options. When unrealistic expectations, whose fulfillment is beyond the reach of the individual, exist, the individual may be left with feelings of perpetual frustration. (Bar-Tal and Bar-Zohar, 1977)

There are further reasons check the temptation to consider internal locus of control as an unquestioned positive and external locus of control as a negative. When decision-makers are exposed shocks, attributing outcomes to external forces can serve as something of a defense mechanism. Rotter (1975) discusses this point, as does the recent behavioral economic literature on attributional style that developed out of Crandall et al. (1965) and Crandall et al. (1962). To summarize, if your teachers are the primary drivers of success in education or the government determines whether you get a job and how much you earn, then failure in these arenas should cause you little psychological distress. On the other hand if it is, in fact, your decisions that determine outcomes, then both success and failure lay squarely on your shoulders.

If a decision-maker's beliefs are shaped by the environment in which they act, then those beliefs should be taken more as signals than as targets. Attempting to change the beliefs without addressing the underlying risk factors that gave rise to them is likely to be fruitless and could clearly be harmful. This is true not only for locus of control, but for other topics of current interest such as hope or aspirations.

Taken as a signal, beliefs can help focus attention on the populations and problems where interventions are most needed. The maize specific locus of control measure used in this study provides a good example of this. The average participant household from Mozambique attributes twice as much influence in maize production to the weather than to her own choice in inputs. This is not true in Tanzania. This should be taken as a sign that households in the Mozambican study areas are highly exposed to weather risk and posses few tools with which to address it.

6 Conclusions

Just as the cognitive revolution in psychology ushered in the rise of a more nuanced treatment of how individuals process experiences, the past few decades have seen economics begin to more fully marry behavioral influences and models of microeconomic behavior (Kremer and Rao, 2017). This is particularly important when applied to decisions facing those in vulnerable communities. As noted in Bertrand et al. (2004), it is not that individuals in these communities posses deviant beliefs or exceptional biases, but that the changes in behavior induced by their circumstances have disproportionately large impacts on their well-being.

Rainfed maize producers in Eastern Africa, like those in the remote, resource poor areas that make up this study, are just such a population. Households in these areas face frequent shocks to their economic position and food security. As climate variability increases, these challenges only grow. In response, many efforts are underway, by both governmental and non-governmental actors, to help households become more resilient. These efforts often take the form of technological advancements or program interventions that require an adoption and compliance decision.

In addition to classical constraints such as limited access to financial services and output markets, the set of internal constraints faced by households in vulnerable communities is often made tighter by their circumstance. In this paper, I have sought to contribute to the literature on the existence and impact of these constraints by studying how locus of control affects farmers' decisions to adopt improved maize varieties in Eastern Africa. I draw on a long history of research in psychology to connect the locus of control construct to economic investment behavior.

While the general locus of control concept used in the existing literature is a good point of departure, for understanding decisions in specific contexts a more activity specific locus of control measure can be developed. I develop such a measure for the context of rainfed maize production and show that farmers hold a wide variety of beliefs about the relative importance of their choices in production. These beliefs are then shown to be predictive of behavior. The third of farmers with the most external locus of control in maize production were shown to be significantly less likely to adopt improved maize varieties in Tanzania and Mozambique.

The most intuitive way for locus of control to affect decision-making in the framework of neoclassical choice theory is for locus of control to affect subjective beliefs about the production function. In particular, I propose that locus of control affects a decision maker's belief about the marginal product of inputs under her control and those controlled by external forces. I present evidence in this direction. I also show that locus of control is conceptually and empirically distinct from risk attitudes and beliefs about the probability distribution of stochastic inputs. While the significance of locus of control is clear from the empirical results of its influence on adoption, more research is needed in order to better elucidate the mechanisms through which these effects occur.

In addition to it's predictive potential, increased attention to locus of control can improve our understanding of the risks facing decision-makers in a variety of contexts. This is particularly true of activity specific locus of control measures. The average maize farmer in the Mozambican sample attributes twice as much influence to weather variation than to her choice of input bundle. In Tanzania, this is only twenty-four percent. Such a result might indicate that households in Mozambique are particularly exposed to weather risk and that there might be large returns to technologies that mitigate the effects of weather risk. If, as I have shown, the beliefs induced by this risky environment also inhibit adoption, then program and policy designers will need to think long and hard about how to get their products into the hands that need them most.

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7 Appendix

7.1 Appendix: Factor Analysis on the Levenson IPC Scales

Constructing a measure of general locus of control in the sample described in this paper begins with the twenty-one Likert-style items listed in Table 13. Seven items pertain to each of three hypothesized control dimensions: internal control, chance factors, and powerful other agents. In this appendix, I describe the process of using factor analysis as a data reduction tool to create a single index, or set of indices, that captures differing beliefs about general control of outcomes for the sample of farmers studied in Mozambique and Tanzania

Initial factor analysis suggests retaining seven factors, using the Kaiser criterion of requiring eigenvalues above unity, or seven factors, locating the point on the screeplot where an "elbow" indicates diminishing returns to additional factors. Figure 9 contains a screeplot of the resulting eigenvalues. The factor analysis routine also warns of a Heywood case, suggesting collinearity among some of the items. The instrument is designed with three factors in mind, so I retain three factors and rotate factor loadings using an oblique quartimin rotation in order to allow for correlation in the factors. This is justified as attribution of control to internal and external forces are believed to be negatively correlated.

Figure 10 plots the rotated factor loadings for all twenty one items. Items with an "I" prefix belong to the internal set of questions; items with a "C" prefix belong to the chance set of questions; and items with a "P" prefix belong to the powerful others set of questions. The figure makes it clear that the three factors cannot easily be identified according to an underlying association. Internal items are not loading primarily on Factor 1, for example.

In order to address both the Heywood case and the lack of a consistent factor structure. I conduct another round of factor analysis on the set of items associated with each Levenson dimension. I retain items that load positively on the primary factor and discard those that do not. Visual inspection of the correlation matrix for all items confirms that the discarded items were not correlated with other items in their own scale or with the items on the other sets of scales. In total, fourteen items were retained.

I once again run the factor analysis routine and consider the resulting screeplot in order to asses the underlying factor structure. The Heywood case has been resolved and a Kaiser-Meyer-Olkin test (0.73) indicates that there is a sufficient common factor structure to warrant data reduction via factor analysis. Both selection criteria now agree that a single factor should be retained (Figure 11). Plotting the resulting factor loadings in Figure 12 also indicates a clear pattern across internal items (negative loadings) and external items (positive loadings). I interpret this factor as "general locus of control". In keeping with psychology convention, larger values are associated with more external locus of control.

Table 13: General Locus of Control Items. Adapted from Levenson (1981) for use in Tanzania and Mozambique

Retained	Internal
X	1. Whether or not I get to be a leader depends mostly on my ability.
X	2. When I make plans, I am almost certain to make them work.
X	3. How many friends I have depends on how nice a person I am.
X	4. I can pretty much determine what will happen in my life.
X	5. I am usually able to protect my personal interestes.
X	6. When I get what I want, it's usually because I worked hard for it.
X	7. My life is determined by my own actions.
Retained	Chance
X	1. To a great extent my life is controlled by accidental happenings.
	2. Often there is no chance of protecting my personal interests ... from bad luck happenings.
X	3. When I get what I want, it's usually because I'm lucky.
	4. I have often found that what is going to happen will happen.
	5. It is not always wise for me to plan too far ahead because many... things turn out to be a matter of good or bad fortune.
X	6. Whether or not I get to be a leader depends on whether ... I'm lucky enough to be in the right place at the right time.
	7. It is chiefly a matter of fate ... whether or not I have a few friends or many friends.
Retained	Powerful Others
X	1. I feel like what happens in my life... is mostly determined by powerful people.
	2. Although I might have good ability, I will not be given ... leadership responsibility without appealing to those in positions of power.
X	3. My life is chiefly controlled by powerful others.
	4. People like myself have very little chance of protecting our personal ... interests when they conflict with those of strong pressure groups.
X	5. Getting what I want requires pleasing those people above me.
	6. If important people were to decide they didn't like me... I probably wouldn't make many friends.
X	7. In order to have my plans work, I make sure that they fit in ... with the desires of people who have power over me.

Figure 9: Screeplot: All 21 General Locus of Control Items

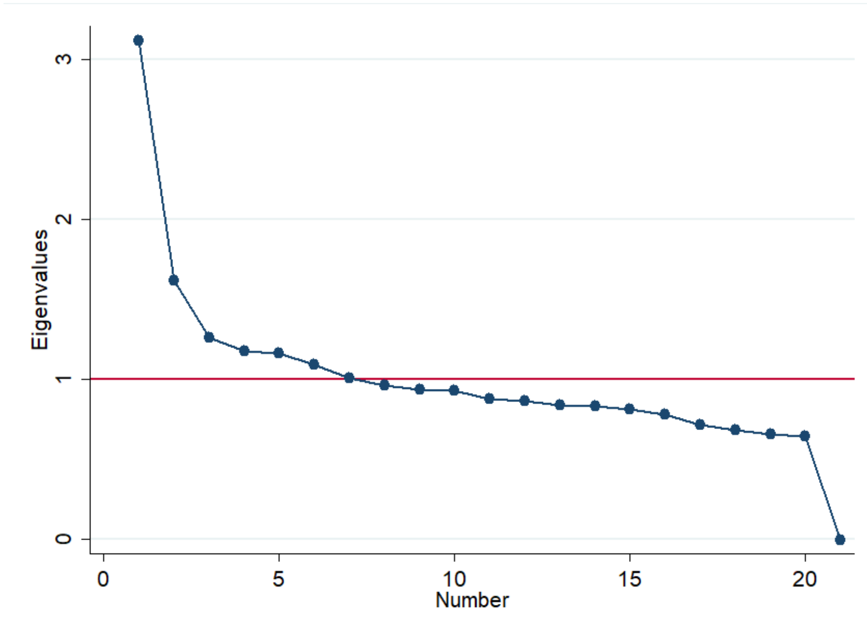


Figure 10: Factor Loadings For First Three Factors Using All 21 General Locus of Control Items

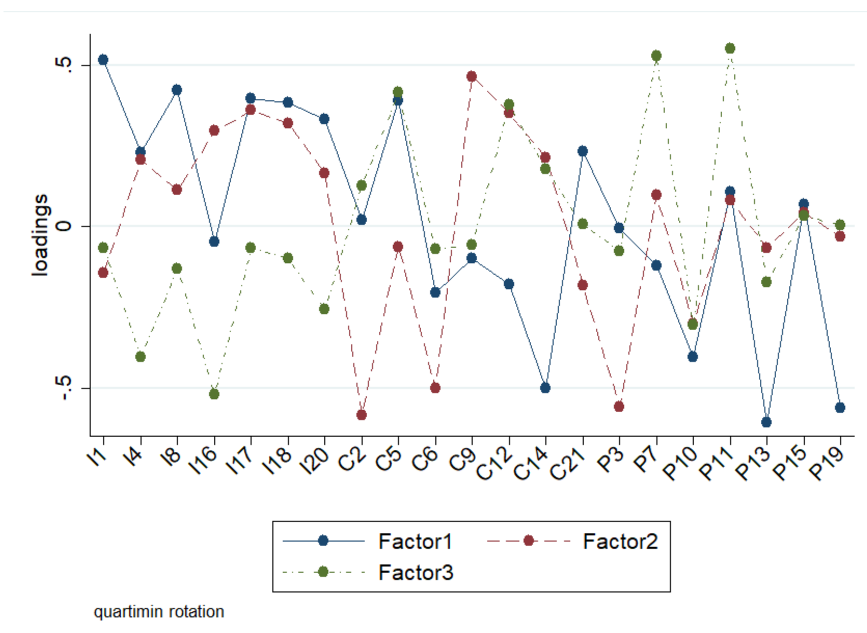


Figure 11: Screeplot: Retained 14 General Locus of Control Items

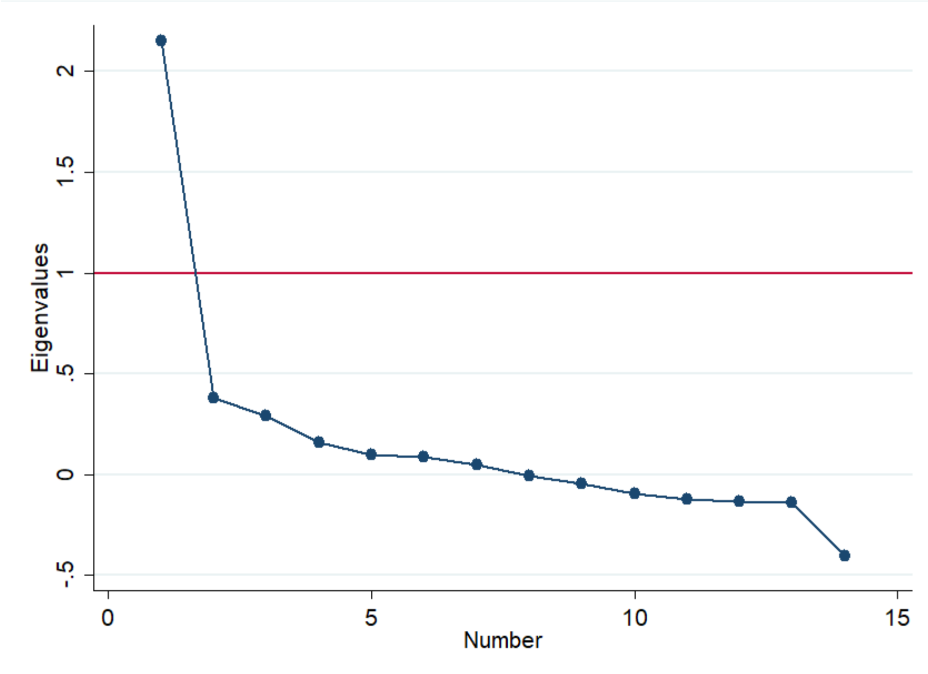
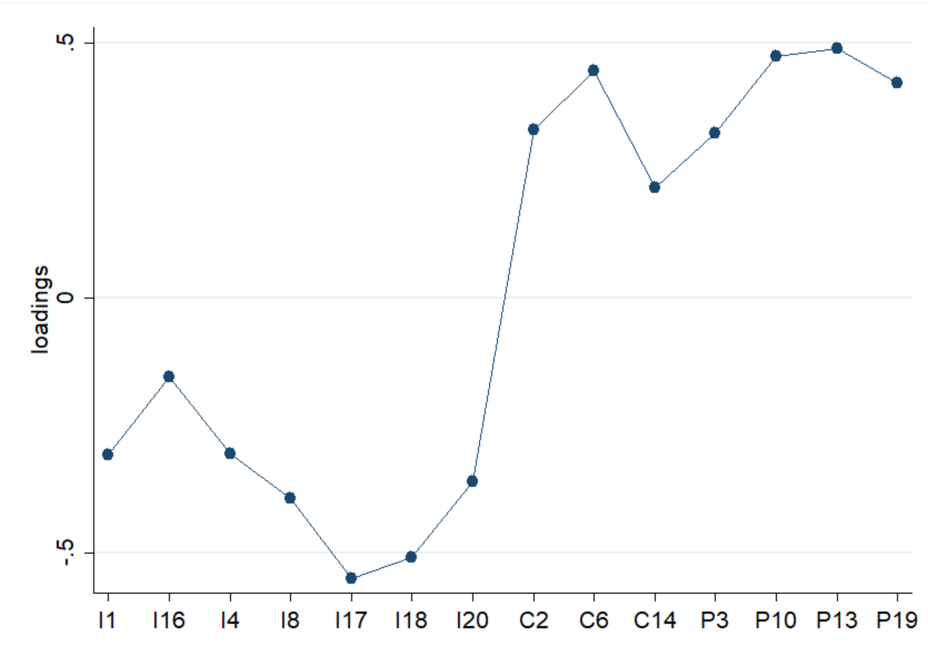


Figure 12: Factor Loadings for 14 Retained General Locus of Control Items



7.2 Appendix: Activity Specific Locus of Control versus Expected Returns to Adoption

Consider the following example with two possible choices by the decision-maker $I \in \{1,2\}$ and two states of nature, $E \in \{1,2\}$.

		E: 1	E: 2
I	1	y_{11}	y_{12}
	2	y_{21}	y_{22}

Assume a positive return to the decision-maker's (DM) choice of $I = 2$ in both states of nature. Also let output for both choices by the DM increase if the state of nature is $E = 2$. No restriction is placed on the relationship between y_{21} and y_{12}. Thus the initial conditions are:

$$\begin{array}{ll} y_{11} < y_{21} & y_{11} < y_{12} \\ y_{12} < y_{22} & y_{21} < y_{22} \end{array}$$

Assigning any probabilities (P_1,P_2) to the states of nature, the expected return to adoption is given by

$$E[R_0] = P_1(y_{21} - y_{11}) + P_2(y_{22} - y_{12}) \tag{16}$$

As in Section 3.1, define activity specific locus of control for $j = I \in \{1,2\}$ and $k = E \in \{1,2\}$ as:

$$LOC_0 = \frac{\sum_j \left(\frac{S_{j\bullet}}{\bar{y}_{j\bullet}}\right)}{\sum_k \left(\frac{S_{\bullet k}}{\bar{y}_{\bullet k}}\right)}$$

Where

$$S_{j\bullet} = \sqrt{\sum_k (y_{jk} - \bar{y}_{j\bullet})^2}$$

$$S_{\bullet k} = \sqrt{\sum_j (y_{jk} - \bar{y}_{\bullet k})^2}$$

$$\bar{y}_{j\bullet} = \frac{1}{2}(y_{j1} + y_{j2})$$

$$\bar{y}_{\bullet k} = \frac{1}{2}(y_{1k} + y_{2k})$$

Given the simple two-by-two space. I write LOC_0 as a single expression made up of four elements.

$$LOC_0 = \frac{\frac{\sqrt{(y_{11}-\bar{y}_{1\bullet})^2+(y_{12}-\bar{y}_{1\bullet})^2}}{\bar{y}_{1\bullet}} + \frac{\sqrt{(y_{21}-\bar{y}_{2\bullet})^2+(y_{22}-\bar{y}_{2\bullet})^2}}{\bar{y}_{2\bullet}}}{\frac{\sqrt{(y_{11}-\bar{y}_{\bullet 1})^2+(y_{21}-\bar{y}_{\bullet 1})^2}}{\bar{y}_{\bullet 1}} + \frac{\sqrt{(y_{12}-\bar{y}_{\bullet 2})^2+(y_{22}-\bar{y}_{\bullet 2})^2}}{\bar{y}_{\bullet 2}}} \tag{17}$$

Where:

$$\begin{array}{ll} \bar{y}_{1\bullet} = \frac{1}{2}(y_{11} + y_{12}) & \bar{y}_{\bullet 1} = \frac{1}{2}(y_{11} + y_{21}) \\ \bar{y}_{1\bullet} = \frac{1}{2}(y_{21} + y_{22}) & \bar{y}_{\bullet 2} = \frac{1}{2}(y_{12} + y_{22}) \end{array}$$

From left to right and top to bottom, call the four elements in Equation 17 $N_{1\bullet}$, $N_{2\bullet}$, $N_{\bullet 1}$, and $N_{\bullet 2}$

7.3 Scaling outcomes by a constant

Consider

		E: 1	E: 2
I	1	y_{11}^{λ}	y_{12}^{λ}
	2	y_{21}^{λ}	y_{22}^{λ}

where $y_{jk}^{\lambda} = \lambda \cdot y_{jk}$

7.3.1 Scaling all outcomes by a constant changes the expected return to adoption.

$$\begin{aligned} E[R^{\lambda}] &= P_1(y_{21}^{\lambda} - y_{11}^{\lambda}) + P_2({y_{22}}^{\lambda} - {y_{12}}^{\lambda}) \\ &= P_1(\lambda y_{21} - \lambda y_{11}) + P_2(\lambda y_{22} - \lambda y_{11}) \\ &= \lambda P_1(y_{21} - y_{11}) + \lambda P_2(y_{22} - y_{11}) \\ &= \lambda E[R_0] \neq E[R_0] \end{aligned}$$

7.3.2 Scaling all outcomes by a constant does not change activity specific locus of control

There are four elements in LOC_λ. From left to right and top to bottom, call these four elements $N^\lambda_{1\bullet}$, $N^\lambda_{2\bullet}$, $N^\lambda_{\bullet 1}$, and $N^\lambda_{\bullet 2}$. The numerator and denominator of each element is of the same form. Consider the numerator of the first element.

$$\sqrt{(y^\lambda_{11} - \bar{y}^\lambda_{1\bullet})^2 + (y^\lambda_{12} - \bar{y}_{1\bullet}\lambda)^2} \tag{18}$$

Note that:

$$\begin{aligned}
\bar{y}^\lambda_{1\bullet} &= \frac{1}{2}(y^\lambda_{11} + y^\lambda_{12}) \\
&= \frac{1}{2}(\lambda y_{11} + \lambda y_{12}) \\
&= \frac{1}{2}\lambda(y_{11} + y_{12}) = \lambda \bar{y}_{1\bullet}
\end{aligned}$$

Then 18 becomes:

$$\begin{aligned}
&\sqrt{(\lambda y_{11} - \lambda \bar{y}_{1\bullet})^2 + (\lambda y_{12} - \lambda \bar{y}_{1\bullet})^2} \\
&= \sqrt{\lambda^2(y_{11} - \bar{y}_{1\bullet})^2 + \lambda^2(y_{12} - \bar{y}_{1\bullet})^2} \\
&= \lambda\sqrt{(y_{11} - \bar{y}_{1\bullet})^2 + (y_{12} - \bar{y}_{1\bullet})^2}
\end{aligned}$$

The first element of LOC_λ is thus:

$$\frac{\sqrt{(y^\lambda_{11} - \bar{y}^\lambda_{1\bullet})^2 + (y^\lambda_{12} - \bar{y}^\lambda_{1\bullet})^2}}{\bar{y}^\lambda_{1\bullet}}$$

$$= \frac{\lambda\sqrt{(y_{11} - \bar{y}_{1\bullet})^2 + (y_{12} - \bar{y}_{1\bullet})^2}}{\lambda \bar{y}_{1\bullet}}$$

$$= \frac{\sqrt{(y_{11} - \bar{y}_{1\bullet})^2 + (y_{12} - \bar{y}_{1\bullet})^2}}{\bar{y}_{1\bullet}}$$

The same is true for each element and thus $LOC_0 = LOC_\lambda$.

7.4 Adding a constant to all outcomes

Consider

		E	
		1	2
I	1	$\tilde{y}_{11}$	$\tilde{y}_{12}$
	2	$\tilde{y}_{21}$	$\tilde{y}_{22}$

where

$$\tilde{y}_{jk} = y_{jk} + \lambda$$

7.4.1 Adding a constant to all four outcomes does not change the expected return

$$\begin{aligned} E[\tilde{R}] &= P_1(\tilde{y}_{21} - \tilde{y}_{11}) + P_2(\tilde{y}_{22} - \tilde{y}_{12}) \\ &= P_1(y_{21} + \lambda - y_{11} - \lambda) + P_2(y_{22} + \lambda - y_{12} - \lambda) \\ &= P_1(y_{21} - y_{11}) + P_2(y_{22} - y_{12}) = E[R_0] \end{aligned}$$

7.5 In nearly all cases, adding a constant to all outcomes changes locus of control

There are four elements in $\tilde{LOC}$. From left to right and top to bottom, call these four elements $\tilde{N}_{1\bullet}$, $\tilde{N}_{2\bullet}$, $\tilde{N}_{\bullet 1}$, and $\tilde{N}_{\bullet 2}$. The numerator and denominator of each element is of the same form. Consider the numerator of the first element.

Consider the element $\tilde{N}_{1\bullet}$ in $\tilde{LOC}$. First, the denominator:

$$\begin{aligned} \bar{\tilde{y}}_{1\bullet} &= \frac{1}{2}(\tilde{y}_{11} + \tilde{y}_{12}) = \frac{1}{2}(y_{11} + \lambda + y_{12} + \lambda) \\ &= \frac{1}{2}(y_{11} + y_{12} + 2\lambda) = \frac{1}{2}(y_{11} + y_{12}) + \lambda \\ &= \bar{y}_{1\bullet} + \lambda \end{aligned}$$

The fact that λ is a positive constant means that I can rewrite the denominator as: The denominator of each element can be written as

$$\bar{y}_{1\bullet} + \lambda = \mu_{1\bullet}\bar{y}_{1\bullet} \tag{19}$$

where

$$\mu_{1\bullet} = \frac{\bar{y}_{1\bullet} + \lambda}{\bar{y}_{1\bullet}} \tag{20}$$

Now, I show that the numerator does not change with the addition of a positive constant:

$$\begin{aligned}
&\sqrt{(\tilde{y}_{11} - \bar{\tilde{y}}_{1\bullet})^2 + (\tilde{y}_{12} - \bar{\tilde{y}}_{1\bullet})^2} \\
=&\sqrt{(y_{11} + \lambda + \bar{y}_{1\bullet} - \lambda)^2 + (y_{12} + \lambda - \bar{y}_{1\bullet} - \lambda)^2} \\
=&\sqrt{(y_{11} - \bar{y}_{1\bullet})^2 + (y_{12} - \bar{y}_{1\bullet})^2}
\end{aligned}$$

I can then write element $\tilde{N}_{1\bullet}$ as:

$$\tilde{N}_{1\bullet} = \frac{1}{\mu_{1\bullet}} \cdot N_{1\bullet}$$

The same is true for the other elements. $L\tilde{O}C$ can then be written:

$$L\tilde{O}C = \frac{\frac{1}{\mu_{1\bullet}} \cdot N_{1\bullet} + \frac{1}{\mu_{2\bullet}} \cdot N_{2\bullet}}{\frac{1}{\mu_{\bullet 1}} \cdot N_{\bullet 1} + \frac{1}{\mu_{\bullet 2}} \cdot N_{\bullet 2}}$$

Thus $L\tilde{O}C = LOC_0$ only if:

$$\frac{1}{\mu_{1\bullet}} \cdot N_{1\bullet} + \frac{1}{\mu_{2\bullet}} \cdot N_{2\bullet} = \gamma \cdot (N_{1\bullet} + N_{2\bullet})$$

And

$$\frac{1}{\mu_{\bullet 1}} \cdot N_{\bullet 1} + \frac{1}{\mu_{\bullet 2}} \cdot N_{\bullet 2} = \gamma \cdot (N_{\bullet 1} + N_{\bullet 2})$$

Where γ is a positive constant. This perfect balance in proportionality seems unlikely and, indeed, in numerical simulations it proves to be so.

7.6 Appendix: Additional Tables and Figures

Table 14: Impacts of Locus of Control on the Adoption of Improved Maize Varieties

	Report Using an Improved Maize Variety			
	(1)	(2)	(3)	(4)
Maize-specific LOC				
Tercile 2	-0.0772***	-0.0267**		
	(0.0150)	(0.0126)		
Tercile 3	-0.108***	-0.0361**		
	(0.0179)	(0.0145)		
LOC_{Maize}			-0.0207**	-0.00316
			(0.00869)	(0.00589)
General LOC				
Tercile 2	-0.0380*	-0.0144		
	(0.0195)	(0.0138)		
Tercile 3	-0.0589***	-0.0186		
	(0.0215)	(0.0172)		
$LOC_{General}$			-0.0383***	-0.0149*
			(0.00987)	(0.00755)
Controls				
Mozambique	-0.0525		-0.0657	
	(0.0432)		(0.0457)	
2018	-0.0368**	-0.0458***	-0.0362**	-0.0454***
	(0.0161)	(0.0161)	(0.0161)	(0.0161)
SPS Points	0.00223***	0.00159***	0.00204***	0.00153***
	(0.000688)	(0.000503)	(0.000694)	(0.000504)
Num. Plots	0.0210***	0.00573	0.0218***	0.00592
	(0.00656)	(0.00569)	(0.00665)	(0.00566)
Education	0.0706***	0.0555***	0.0714***	0.0550***
	(0.0213)	(0.0143)	(0.0214)	(0.0143)
Risk Index	0.0210	0.0330**	0.0210	0.0327**
	(0.0140)	(0.0130)	(0.0139)	(0.0128)
E[Good Rain]	0.00493	0.00377	0.00485	0.00386
	(0.00534)	(0.00457)	(0.00530)	(0.00459)
E[Poor Rain]	-0.00155	0.00102	-0.00160	0.00114
	(0.00663)	(0.00463)	(0.00660)	(0.00464)
Drought	0.0497**	0.0144	0.0511**	0.0137
	(0.0239)	(0.0178)	(0.0245)	(0.0179)
Constant	0.388***	0.393***	0.334***	0.368***
	(0.0654)	(0.0453)	(0.0627)	(0.0416)
Observations	5355	5355	5355	5355
R^2	0.050	0.282	0.045	0.282

Robust standard errors in parentheses

Strata FE

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 15: Heterogeneous Impacts to a Randomized Marketing Intervention

	Use Improved Maize		Use Drought-tolearnt Maize	
	(1)	(2)	(3)	(4)
$y_{i,t-1}$	0.161***	0.165***	0.0644***	0.0659***
	(0.0189)	(0.0182)	(0.0186)	(0.0189)
Treat	0.282***	0.261***	0.390***	0.426***
	(0.0225)	(0.0282)	(0.0167)	(0.0222)
Maize-Specific LOC				
LOC_{Maize}		-0.00698		-0.000793
		(0.0106)		(0.00400)
Treat × LOC_{Maize}		0.00966		-0.0163**
		(0.0133)		(0.00824)
General LOC				
$LOC_{General}$		-0.0480***		-0.000986
		(0.0146)		(0.00750)
Treat × $LOC_{General}$		0.0297*		-0.0162
		(0.0176)		(0.0125)
Constant	0.248***	0.266***	0.0432***	0.0391***
	(0.0147)	(0.0230)	(0.0116)	(0.0143)
Observations	5563	5355	6210	5816
R^2	0.238	0.239	0.223	0.232

Village clustered standard errors in parentheses, Strata FE Used

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 13: Expected Harvest Gain From Adopting Improved Maize Seeds Across Deciles of the Locus of Control Distribution

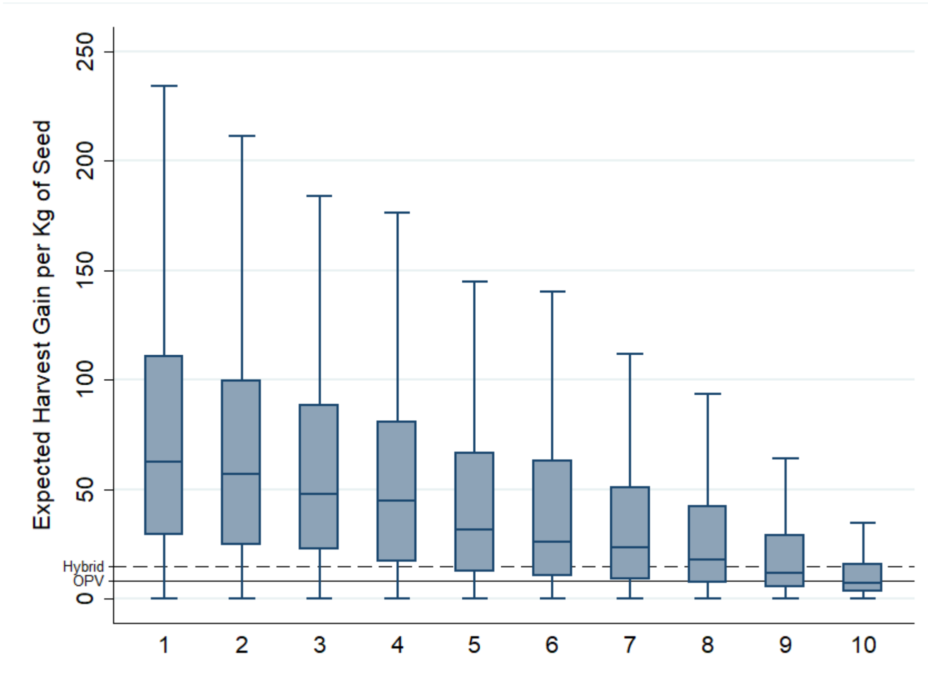


Figure 14: Expected Harvest Gain From Adopting Improved Maize Seeds Across Terciles of the Locus of Control Distribution

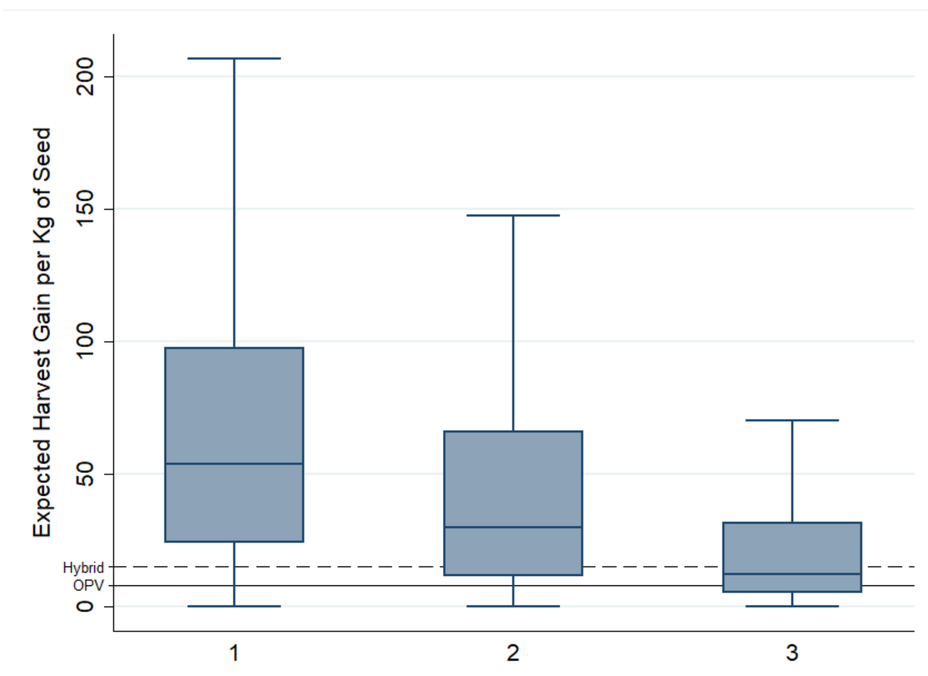


Table 16: Community Meeting Attendance and Seed Purchases: By Year

	2016		(2017)	
	Attend	Purchase|Attend=1	Attend	Purchase|Attend=1
Maize-specific LOC				
Tercile 2	-0.102**	-0.0165	-0.0330	-0.0513
	(0.0404)	(0.0465)	(0.0519)	(0.0613)
Tercile 3	-0.125***	0.0473	-0.0270	0.0457
	(0.0406)	(0.0551)	(0.0516)	(0.0556)
General LOC				
Tercile 2	0.0172	0.0147	-0.0351	-0.0122
	(0.0350)	(0.0358)	(0.0412)	(0.0543)
Tercile 3	0.0695*	-0.0308	-0.0399	-0.0294
	(0.0379)	(0.0380)	(0.0489)	(0.0699)
Constant	0.696***	0.780***	0.457***	0.715***
	(0.0446)	(0.0533)	(0.0534)	(0.0724)
Observations	714	463	711	293
R^2	0.016	0.007	0.002	0.007

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$