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Weather Risk, Contracts, and Technology Adoption: Evidence from Ethiopia

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Abstract

The study explores the impact of weather risk on the use of chemical fertilizers by farmers in the presence of insurance and credit market imperfections. We argue that an important channel through which weather risk influences the adoption of new agricultural technology is by altering the optimal land and labor contracts farmers choose which in turn, through their different risk-sharing and incentive mechanisms, influence both the probability of technology adoption and the intensity of its use that ultimately affect overall agricultural productivity. We test this claim using panel data from Ethiopia and find that in villages that are characterized by high long term rainfall variability and significant weather shocks, farmers are more likely to adopt sharecropping contracts, as opposed to fixed rental contracts, under which they are less likely to adopt and intensively use productivity-boosting chemical fertilizers. Thus, we contend, by discouraging the transfer of land to more efficient farmers under rental contracts —thereby resulting in a loss of the potential grains from trade—and by increasing farmers' propensity to use sharecropping contracts to cope with production risk —which are bedeviled by moral hazard problems—weather risk reduces the use of chemical fertilizers and decrease agricultural productivity considerably.

JEL classification: O12, O33, P14, Q12, Q15
Key Words: Technology Adoption, Contracts, Sharecropping, Climate Change; Empirical Contact Theory

I. Introduction

There is a growing concern about the adverse impacts climate change would have on the short term and long term welfare of societies both in developed and developing economies. The most recent assessment report by the Intergovernmental Panel on Climate Change (IPCC) warns of "severe, pervasive, and irreversible" impacts of global warming, particularly on poor communities who are ill equipped to adapt to and mitigate the effects of climate change (IPCC, 2014). Regardless of whether these changes are mainly attributed to anthropogenic or natural causes, weather shocks frequently put the lives of millions of farmers in poor countries at risk from crop failure and the death of animals that serve as a buffer in times of economic hardship. This is no more evident than in Ethiopia where around 8 million people are chronically food insecure, and even as recent as 2016 the government estimates that an additional 9.7 million people needed immediate food assistance (USAID, 2016).

In this study, we argue that one of the most important channels through which climate change potentially affects the long-term standard of living and welfare in many developing economies is by influencing overall agricultural productivity and economy-wide structural transformation through its effect on farmers' choice of technology. Hence, we explore how weather risk influences technology adoption by Ethiopian farmers in the presence of credit and insurance market imperfections, and empirically estimate the impact of weather risk on overall agricultural productivity by looking at its effect on farmers' choice of technology. The focus on technology choice to evaluate the potential impact of climate change on agricultural productivity is justified since many economists and agricultural experts view low adoption of chemical fertilizers and modern seeds as the primary cause for the stagnation observed in African agriculture, which provides the livelihood for a significant portion of the population (Duflo et al., 2011; Sachs, 2004).

Furthermore, we contend that, apart from the direct impact that weather shocks have on farmers' choice of crops and technology, an important mechanism through which climate change potentially influences technology adoption is by altering the optimal land and labor contracts farmers enter into. Because these contracts do have different incentives and risk-sharing mechanisms embodied in them, they influence farmers' decision to adopt new technology, in particular when the returns of the new technology are uncertain. This will in turn affect overall agricultural productivity.

To empirically examine this, we use panel data from Ethiopia to link long term rainfall variability with farmers' choice of labor and land contracts, and explore how the choice of these contracts in turn influences the types of technology farmers adopt. Next, we tie the choice of technology with agricultural productivity to assess the potential welfare impacts of adverse climate change. By employing nationally representative household panel data from Ethiopia collected by the World Bank and the Ethiopian Economic Association in 2006 and 2010, we find that in villages that are characterized by high long term rainfall variability and significant weather shocks, farmers are more likely to adopt sharecropping contracts, as opposed to fixed rental contracts, under which they are less likely to adopt and intensively use productivity-boosting chemical fertilizers. Therefore, we argue, by discouraging the transfer of land under rental contracts to more efficient farmers—resulting in a loss of the potential grains from trade—and by increasing farmers' propensity to use sharecropping contracts to cope with production risk —which are bedeviled by moral hazard problems—weather risk reduces the use of chemical fertilizers, thereby lowering overall agricultural productivity.

In particular, using a multinomial logit model, we find that on average an increase in main season rainfall by one standard deviation relative to the mean reduces the probability that a farmer would rent in land by about 30% while it increases the probability that she would enter into a sharecropping arrangement by about 25%, controlling for potentially confounding plot and household characteristics. Furthermore, the probability that a landlord contributes fertilizer and other inputs to the tenant under sharecropping contracts declines by around 12.5% for a one standard deviation increase from the mean in main season rainfall.

This is important because the probability of using chemical fertilizers on plots under rental contract, compared to plots under autarky or sharecropping contracts, is around 12% higher in addition to the fact that the intensity of fertilizer use in the former is greater than the latter by about 25-30 kg per hectare, again controlling for observable relevant plot and household characteristics and adjusting for endogenous selection into contracts. Finally, we estimate production functions under the different contract regimes using an endogenous switching regression framework to assess the impact of weather risk on agricultural productivity through its effect on the choice of agricultural technology, again allowing for the possibility that contract choice is endogenous. Accordingly, we find that a one percent increase in fertilizer use increases yield by about 0.13 % in own plots and plots under fixed rental contract, which are both theoretically free from moral hazard problems, while the corresponding effect under share contracts is lower.

Overall, the empirical evidence we present suggests that in the absence of insurance markets, weather risk alters the land and labor contracts farmers choose and this has implications on the adoption of modern technology and overall agricultural productivity. Hence, policies aimed at addressing insurance and credit market imperfections can help mitigate the adverse impacts climate change may have on agricultural productivity by promoting rental market participation, which would result in the gains from trade, and potentially eliminating the moral hazard effect associated with sharecropping contracts that farmers adopt to cope with production risk.

II. **Conceptual Framework**

In this section, we develop a simple model that links changes in weather risk, contracts, and technology adoption in the presence of credit market imperfections. To that end, we introduce production risk coming from weather shocks associated with climate change in the traditional principal-agent framework. This will enable us to analyze how weather risk affects technology adoption directly, and indirectly by influencing the farmer's optimal choice of land and labor contracts which ultimately influences the use of technology on the specific plot of land.

Thus, consider a landlord with total land size T. The landlord can potentially enter into three types of contracts: (1) she can farm the land using hired labor (wage contract) with or without family labor, (2) she can rent out the land (fixed rental contract), or (3) she can enter into a sharecropping arrangement. The sharecropping contract may involve cost-sharing arrangements as well. I further assume the landlord can enter into these contracts with a large number of identical tenants but only with one tenant at a time.[1]

The production function $f: R_+^2 \to R_+$ is strictly concave and is assumed to be twice differentiable in both labor and fertilizer, the two inputs employed along with managerial (entrepreneurial) skill that captures the efficiency in the management of the farm, $A_i \in R_{++}$, where $i \in \{landlord, tenant\}$; $A_l \in R_{++}$ and $A_t \in R_{++}$ represent the managerial skills of the landlord and tenant, respectively. More specifically, the production function is specified as $Q = A_i f(x, l, \theta)$, where x and l denote

[1] To facilitate the discussion, assume the landlord is female and the tenant is male.

fertilizer and labor, and θ represents production uncertainty (such as weather risk) that make the returns on investment in the technology uncertain. We assume that input choices are made at the beginning of the production cycle.

To simplify our analysis assume production risk, θ, enters multiplicatively i.e. $f(x,l,\theta) = \theta f(x,l)$ and $E\theta = 1$..

Thus, we can express the income of the landlord, Y_l, as:

$$Y_l = (1-\alpha)A\theta f(x,l) - (1-\beta)p_x x + r \qquad (1)$$

where $\alpha \in [0,1]$ is the tenant's share of output, $\beta \in [0,1]$ represents the tenant's share of input cost and $r \in R$ is rent received by the landlord. We have fixed the price output at 1, and p_x denotes the price of fertilizer

Thus, equation (1) says the expected income of the landlord is:

$$EY_l = (1-\alpha)Af(x,l) - (1-\beta)p_x x + r$$

Similarly, the income of the tenant, Y_t, can be expressed as:

$$Y_t = \alpha A\theta f(x,l) - \beta p_x x - r \qquad (2)$$

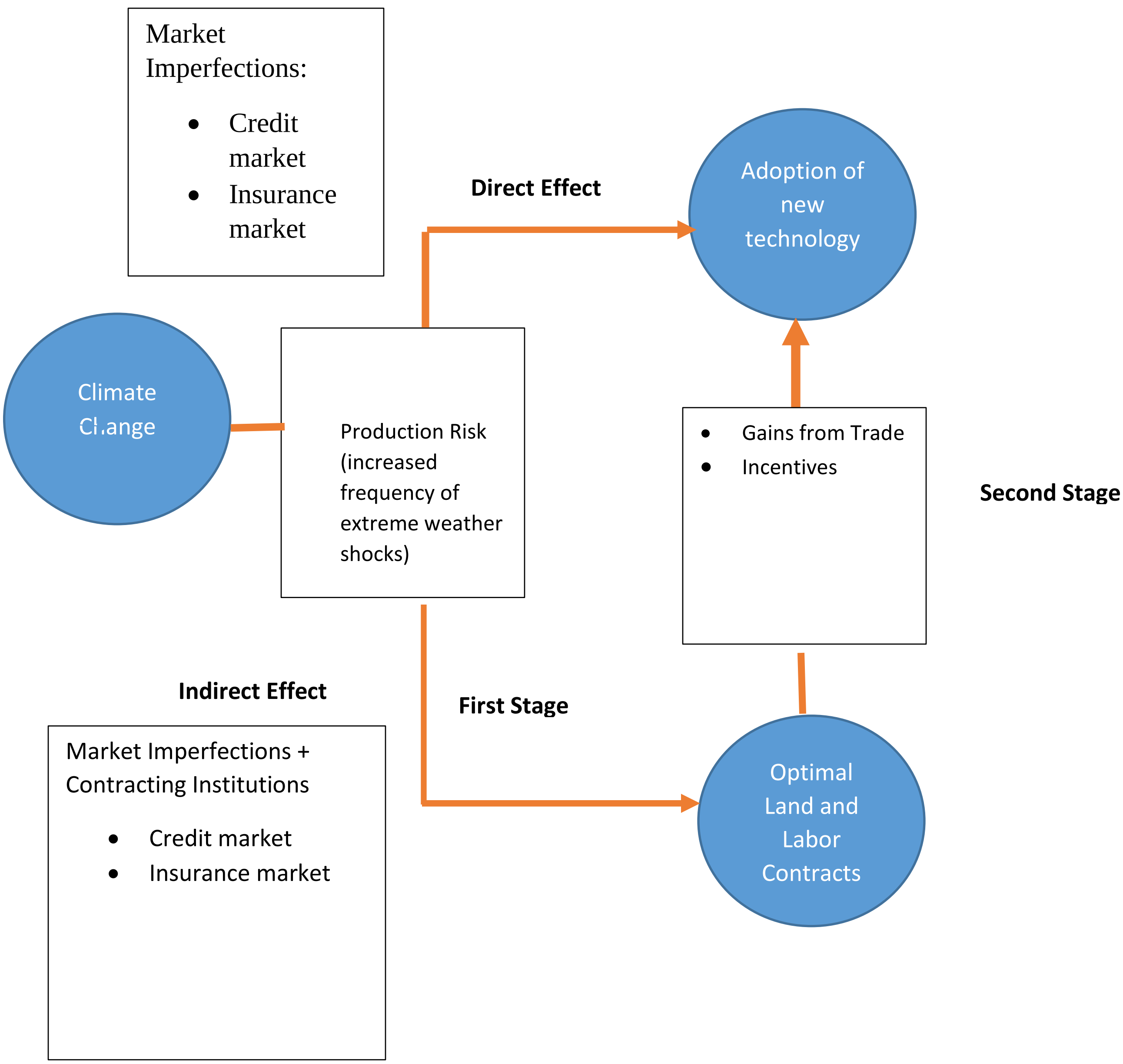
Note that under rental contract we have $\alpha = \beta = 1$ and $r > 0$, and under wage contract we will have $\alpha = \beta = 0$ and $r < 0$. We have pure output sharing and input-put sharing contracts under sharecropping.[2] That is,

(1) pure output sharing contract : $\alpha \in (0,1)$, $\beta = 0$ and $r \geq 0$
(2) input-output sharing contract: $\alpha \in (0,1)$, $\beta \in (0,1)$ and $r \geq 0$

Let U represent the utility function of the tenant. As it is standard in the literature, we assume the utility of the tenant is separable into income and effort. Hence, denote $\psi(l): R_+ \to R_+$ as the disutility associated with work. We assume $\psi' > 0$ and. $\psi'' > 0$.

[2] See Laffont and Matoussi (1995) for a similar specification of contracts.

Figure 1: Linking Climate Change and Technology Adoption



First assume (i) the landlord is risk neutral, (ii) the tenant is risk averse, (iii) all inputs are observable by the landlord (and hence there is no incentive problem/moral hazard). The assumption that all inputs are observable by the landlord implies the landlord does not have to worry about the tenant's incentive compatibility constraint. Hence, the landlord's program is given by:

$$\max_{\alpha,\beta,r,x,l} (1-\alpha)A_l\, f(x,l) - (1-\beta)\,p_x x + r$$

subject to:

$$EU\left(\alpha A_t \theta f(x,l) - \beta p_x x - r\right) - \psi(l) \geq U(\overline{w}) \text{.............} (\lambda)$$

$$0 \leq \alpha \leq 1 \text{............................} (\ \mu\ )$$

where $U(\overline{w})$ represents the tenant's reservation utility, and λ and μ are the Lagrange multipliers of the respective constraints. Suppose $A_t > A_l$ and define the marginal risk premium of the tenant as $\rho \equiv 1 - \dfrac{EU'\theta}{EU'}$.[3] Denote α^* as the optimal value of α that solves the landlord's program above.

PROPOSITION: Under assumptions (i)-(iv), if $\rho > \dfrac{A_t - A_l}{A_t}$, then the landlord chooses wage contract; if $\rho < \dfrac{A_t - A_l}{A_t}$, then fixed rental contract is the optimal contract.

<u>Proof **:**</u>

The first order conditions of the landlord's program are:

$$(1-\alpha)A_l \frac{\partial f}{\partial l} + \lambda\left(\alpha EU'\theta A_t \frac{\partial f}{\partial l} - \psi'\right) = 0$$

$$(1-\tau(R))(1-\alpha)A_l \frac{\partial f}{\partial x} - (1-\beta)p_x + \lambda EU'\left(\alpha\theta A_t \frac{\partial f}{\partial x} - \beta p_x\right) = 0$$

$$\left([-A_l\, f(x,l)] + \lambda EU'\theta A_t\, f(x,l)\right) - \mu \leq 0 \quad \text{and}$$

$$\left(\left([-A_l\, f(x,l)] + \lambda EU'\theta(1-\tau(R))A_t\, f(x,l)\right) - \mu\right)\alpha = 0$$

$$\alpha - 1 \leq 0 \text{ and } \mu(\alpha - 1) = 0$$

$$(1 - \lambda EU') = 0$$

[3] The marginal risk premium measure measures how the risk premium changes with output/income. Note that $\rho = -Cov(U',\theta) > 0,$ for a risk averse agent.

From the complementary condition involving α we have

$$\left(\left[-A_l f(x,l)\right]+\lambda EU'\theta A_t f(x,l)-\mu\right)\leq 0$$

First Suppose that $\alpha \neq 1$. This implies $\mu = 0$. Hence, we have

$$\left(\left[-A_l\right]+\frac{EU'\phi}{EU'}A_t\right)\leq 0, \text{ as } \lambda=\frac{1}{EU'}$$

Rearranging the above equation yields,

$$1-\frac{A_l}{A_t}\leq 1-\frac{EU'\phi}{EU'}$$

From the complementarity condition we see that, if $1-\frac{EU'\theta}{EU'}>\frac{A_t-A_l}{A_t}$, $\alpha^*=0$.

Now we can get the value of μ by setting $\alpha = 1$, which yields

$$\mu=-A_l f(x,l)+\frac{EU'\theta}{EU'}A_t f(x,l)$$

From the complementarity condition that involves μ, we can see that if $\mu > 0$, then $\alpha^* = 1$

But $\mu > 0$ only if $1-\frac{EU'\theta}{EU'}<\frac{A_t-A_l}{A_t}$. Q.E.D.

The condition in Proposition 1 shows the two counterbalancing effects the landlord needs to consider in choosing the optimal contract. On one hand, if the tenant is too risk averse, he will apply fewer units of inputs if he rents the land, and hence his profit would be very low which would limit the amount of rent the landlord can extract from him. On the other hand, if the tenant is much more productive than the landlord in his managerial capacity, the rent the landlord can charge the tenant would be higher. Hence, Proposition 1 says if the risk premium is greater than the productivity differential between the two parties, then the landlord would find it optimal to hire the tenant as a wage laborer, and choose the level of inputs herself while pushing the tenant to his reservation utility.

By the same token, if the productivity differential dominates marginal risk premium, then fixed rental becomes the optimal contract, and the landlord transfers the land to the tenant.

This implies that fertilizer demand is low under the weather risk due to two effects: (1) the direct of impact of production uncertainty arising from weather shocks on fertilizer demand; and (2) the indirect impact of weather shocks on technology adoption by preventing gains from trade (i.e., influencing contract choice). That is, under the conditions specified in Proposition 1, the presence of the extreme weather shocks implies the landlord needs to provide full insurance to the risk averse agent by offering her wage contract, and this results in the potential loss of gains from trade when $\rho > \frac{A_t - A_l}{A_t}$.

When inputs are not fully observable or the cost of monitoring is prohibitively costly, the landlord solves the optimization problem described above with the following two incentive compatibility constraints of the tenant:

$$EU'\theta\alpha A_t \frac{\partial f}{\partial l} - \psi' = 0$$

$$EU'\left(\alpha\theta A_t \frac{\partial f}{\partial x} - \beta p_x\right) = 0$$

This results to the classical result that sharecropping is the optimal contract choice (note that wage contracts does not solve the incentive compatibility constraint). In this case, even when there is no difference in the managerial capacity between the landlord, there will be a suboptimal use of fertilizer on the land when sharecropping is chosen due to aversion towards weather shocks as fixed rental contract would not be chosen and the incentive (moral hazard) problems associated with sharecropping contracts persists (moral hazard problems do not exist under rental contracts).

Finally note that even in the absence of weather risk, credit market imperfections on the tenant can potentially exclude a rental contract. To see this suppose the tenant is credit constrained, and his credit constraint is given as:

$$\beta p_x N + r - p_x (N - x) \leq W_t \,,$$

where W_t represents the tenant's wealth (or working capital)

Substitute into her rationality constraint in equation (5) to get[4]

$$\alpha \leq \frac{\overline{w} + W_t + \psi(l)}{\left(1 - \tau(R)\right) A f(x,l)} \qquad (3)$$

Equation (10) says that severe credit constraints can potentially exclude rental contract. That is, if the tenant's wealth is very low it is possible that $\alpha < 1$. (See Stiglitz, 1974 and Laffont, 1995 for a similar discussion)

III. Data and Descriptive Statistics

3.1 Data

The data for the study were obtained from household surveys conducted by the World Bank (WB) and Ethiopian Economic Association (EEA) in 2006 and 2010. These surveys cover over 2300 households that are randomly selected from 115 rural Ethiopian villages in four regional states in Ethiopia: Amhara, Oromia, Southern Nations, Nationalities and Peoples (SNNP), and Tigray regional states.[5] According to the Ethiopian Statistical Authority, the population in these regions accounted for 86% of the estimated 75.1 million and 79.7 million population of Ethiopia in 2006

[4] Note that the tenant's real expenditure is on fertilizer is $\beta p_x N + r - p_x (N - x)$. Furthermore, his rationality constraint is binding.

[5] Ethiopia is a federal republic with 7 regional states and 2 chartered cities.

and 2010, respectively.[6] We obtained rainfall data for about 184 stations in the country from the Ethiopian National Meteorology Agency.[7] We link this household survey with the long term rainfall data from the National Meteorology Agency using the geographic coordinates of the locations of farmers to explore the impact that frequent weather shocks have on their choices of technology and its implications on agricultural productivity.

3.2 Descriptive Statistics

In Table 1, we present descriptive statistics on how technology choice is linked to the choice of land and labor contracts. The proportion of plots that are cultivated using modern seeds is higher under rental contract than those under sharecropping contracts or plots farmed by households using their own family labor alone (autarky).[8] Specifically, 19% of parcels under fixed rental contract were farmed using modern seeds in 2006. The corresponding figure is 10% for parcels under share contracts and 13% under autarky. In 2010, 18% parcels under fixed rental contracts were farmed by employing modern seeds as opposed to 14% and 21% under share and wage contracts, respectively.[9] In the same year, 15% for plots of land under autarky were farmed using modern seeds.

[6] The population of Ethiopia is estimated to be over 94.1 million making the country the second most populous country in Africa after Nigeria.

[7] Based on the geographic coordinates of the villages and stations, we computed the distance between each station and the villages in the sample and assigned the rainfall data of the nearest station to each village.

[8] We say a farmer has used modern seed on the parcel if he plants one or more crops using a high-yield variety.

[9] We consider all plots where the use of hired labor is greater than family labor to be under wage contracts.

Table 1 : Technology Use by Contract Type

Variable	2006				2010			
	Autarky	Wage Contract	Share Contract	Fixed Rental Contract	Autarky	Wage Contract	Share Contract	Fixed Rental Contract
Use of modern seeds	0.13	0.19	0.10	0.19	0.15	0.21	0.14	0.18
Use of modern fertilizers	0.39	0.37	0.42	0.68	0.43	0.33	0.59	0.72
Intensity of Fertilizer Use (kg/ha)	54.68	68.74	59.76	104.00	58.7	64.1	77.03	97.13
Good soil quality	0.58	0.66	0.51	0.48	0.62	0.67	0.57	0.69
Medium Soil quality	0.30	0.25	0.33	0.43	0.30	0.25	0.31	0.24
Flat Sloped	0.75	0.72	0.78	0.83	0.77	0.72	0.79	0.90
Slightly Slanted	0.20	0.25	0.19	0.14	0.20	0.24	0.19	0.09
Household Size	7.06	6.46	6.86	7.61	7.5	7.2	7.61	8.33
Head is illiterate	0.47	0.35	0.31	0.31	0.48	0.33	0.35	0.24
Female- headed household	0.09	0.17	0.03	0.05	0.11	0.10	0.03	0.04
Value of asset in Birr	828.33	1089.74	1037	1369	2503.94	3809.43	3414.61	6767.60

Source: Authors' computation from WB/EEA survey

The descriptive statistics also show that the probability of adopting chemical fertilizers is highest under rental contract. Chemical fertilizers were applied to 68% of parcels under rental contracts in 2006. The analogous figure is 37% for plots under wage contracts, 42% under share contracts, and 28% under autarky. In 2010 72% of parcels under fixed rental contracts had modern fertilizers as opposed to only 39% under autarky. Chemical fertilizers were applied to 59% of plots under share contracts and wage contracts in 2010. This high use of fertilizers under share contracts was mainly driven by high fertilizer use under input-output sharing contracts.

The intensity of fertilizer use is also the highest under fixed rental contracts. In 2006, chemical fertilizer use was 104 kg per hectare for plots under fixed rental contracts as opposed to 54.7 kg per hectare and 59.8 kg per hectare under autarky and share contracts, respectively. The figure was 69 kg per hectare for wage contracts. The same pattern is observed 2010; the intensity of fertilizer use on plots of land under fixed rental and wage contracts was 96.2 kg per hectare and 64 kg per hectare, respectively. The corresponding figures are 80 kg per hectare for share contracts and 58.7 kg per hectare for plots of land under autarky.

Although the probability of adopting modern seeds and fertilizer and the intensity of fertilizer use is relatively higher under rental contracts, it is important to observe that households who adopt these two type of contracts tend to be much wealthier and more educated. This implies we cannot readily ascribe the choice contracts as the causal factor that influences the technology adoption decision of farmers.

In Tables 2 -5 in the appendix , we present the characteristics of households who live in villages that have historically faced high to medium weather and other production shocks along with the plot and household characteristics of farmers who reside in low-risk agro ecological zones for the years 2006 and 2010.

Accordingly, households in villages where production risk is lower are relatively well to do, as reflected in both the value of their household assets and agricultural endowments, and are more likely to use modern fertilizers and use fixed rental contracts. Nevertheless, because the households in these villages are fundamentally different in many socio-economic characteristics, we cannot readily deduce any causal inferences from these descriptive statistics. Thus, we devise an empirical strategy that control for endogenous selection into different contract regimes at the household level.

IV. **Econometric Results**

The econometric strategy we adopt aims at estimating the impact of long term rainfall variation on technology adoption through its effect on agricultural contracts. This involves two stages. In the first stage, we link long term rainfall variation with contract choice. Here we adopt a multinomial logit framework to estimate the impact of weather risk on the type of land and labor contracts farmers choose. In the second stage, contract choice is linked with the decision to adopt agricultural technology. Finally, we estimate a production function using switching regression framework to assess the productivity effect of weather risk through its effect on technology choice.

4.1 Estimating the Impact of Weather Shocks on Technology Adoption through Contract Choice

4.1.1 Linking Long term rainfall variability and Contract Choice

We first explore the relationship between of long term rainfall variability in the village on the choice of land and labor contracts by farmers. Towards this end, we run a multinomial logit model and report the results in Table 2. Thus, the response probabilities of contracts to changes in weather variation and other plot and household characteristics is given by:

$$P(y_{ikt} = j|x_{ikt}) \frac{\exp(x\beta_j)}{1 + \sum_{h=1}^{J} x\beta_h}, j = 1, \dots, J$$

Where y_{ikt} is the contract choice of household i on plot k at time t . There are essentially four contract types we consider in the empirical analysis: wage contracts, fixed rental contract, output-sharing contract, and input-output sharing contracts. The base category is autarky where the household uses only family labor to farm its plots.[10] x_{ikt} denotes other household and plot characteristics. We obtained rainfall data for about 184 stations in the country from the Ethiopian National Meteorology Agency and computed the coefficient of variation (CV) of main season long term rainfall for each station since 1970, depending on data availability. We then assign the CV of main season rainfall of the nearest station to each village in our sample and use it as the measure of the magnitude of weather risk that households in a given village face. We then proceed to estimate the impact variation in main season rainfall on the type of land and labor contracts farmers choose. Clearly, our empirical strategy relies heavily on the assumption of strict exogeneity of weather risk (rainfall variation).

Our use of long term rainfall variability at the village level to measure weather risk is justified because our main interest is to understand how climate change, which a long-term phenomenon, potentially influences the evolution of agricultural contracts , thereby influencing the choice of agricultural technology and agricultural productivity in the long run. We present the econometric results for the years 2006 and 2010 in Table 2 and Table 3.

Consistent with our hypothesis, our findings indicate that the choice of contracts is influenced by the presence of weather risk as measured by the coefficient of variation of long term rainfall. Households that live in villages with higher rainfall variability are more likely to choose output-sharing contracts, and less likely to adopt fixed rental contracts. More specifically, we find that on average a one standard deviation increase in main season rainfall relative to the mean reduces the probability that a farmer would rent in land by about 30% while it raises the probability of

[10] Note that it is important to make a distinction between a household that does not hire labor because it is optimal to do so and a household that does not hire labor due to labor and credit market imperfections. Thus, it is important to control for adult family labor and household assets in our analysis.

entering into a sharecropping arrangement by 25%, controlling for confounding plot and household characteristics. This is intuitive: under fixed rental contracts the farmer bears all production risk and thus is less likely to rent in land in villages where weather risk is high. Furthermore, the probability that a landlord contributes fertilizer and other inputs under sharecropping arrangement declines by about 12.5% when rainfall variability increases by one standard deviation relative to the mean. In the appendix, we also present econometric results where we explore how weather risk influences the choice of contract from both the demand and supply side i.e. whether a household is likely to rent in land as opposed to rent out, or share-in land as opposed to share out. The qualitative results we find are similar : weather risk reduces rental market participation considerably while the it raises the propensity of farmers to share-out their land (See Table A5 and Table A6) .

4.1.2 Linking Contracts and Technology Adoption

A. The Impact of Contracts on the Probability and Intensity of Technology Adoption

This section presents regression estimates of the probability of using modern fertilizers conditional on household and plot characteristics and the choice of crops. We run three initial regressions: linear probability, linear probability fixed effects model, and logit model, controlling for observable household and plot characteristics, as well as the type of crop produced by the farmer. Table 4 presents the regression results. The base outcome for contract choice is autarky. The dependent variable is a dummy variable that indicates whether the farmer used chemical fertilizers on the plot. All the regression models provide evidence that the household is more likely to use modern fertilizers under fixed rental contracts and input-output sharing contracts than under autarky and pure output sharing arrangement. In addition, as predicted by theory, all three regression results provide evidence that farmers are less likely to use modern fertilizers on plots under wage contracts.

Table 2 : Linking Weather Risk with Contract Choice: A Multinomial Logit Framework (2006)

VARIABLES	output share	output/input share	rental contract
rainfall coefficient of variation	2.840***	-9.979***	-2.803***
	(0.650)	(1.530)	(0.405)
Number of years possessed	-0.268***	-0.319***	-0.0655***
	(0.00902)	(0.0249)	(0.00323)
Dummy: soil quality lem	-0.313**	0.668	-0.146
	(0.145)	(0.422)	(0.0985)
Dummy: soil quality lem-te	-0.193	0.887**	0.201**
	(0.153)	(0.426)	(0.102)
Dummy: plot is irrigated	0.0478	0.128	-0.401***
	(0.218)	(0.546)	(0.156)
Dummy: topography meda (flat)	0.575**	0.256	0.461***
	(0.270)	(0.514)	(0.172)
Dummy: topography dagetama (sloppy)	0.277	0.253	0.0183
	(0.285)	(0.542)	(0.183)
Oxen days	-0.00366	0.0299***	0.0135***
	(0.00646)	(0.00748)	(0.00319)
Family labor	-0.00144	-0.00683*	-0.00350***
	(0.00163)	(0.00410)	(0.00108)
Hired labor	0.00523*	-0.000775	0.00301
	(0.00305)	(0.00731)	(0.00190)
Household size	0.118***	0.143***	0.133***
	(0.0208)	(0.0406)	(0.0133)
Dummy: female headed household	-0.872***	-14.90	-0.158
	(0.284)	(736.8)	(0.138)
Dummy: head can read and write	-0.0290	-0.488**	0.0880
	(0.102)	(0.213)	(0.0647)
Dummy: farming (family) is the primary activity of the head	0.121	1.263	-0.136
	(0.254)	(1.035)	(0.140)
Dummy: roof material of main house is corrugated metal	0.401***	0.602**	0.0711
	(0.114)	(0.270)	(0.0702)
Number of rooms of main house	-0.0957*	0.0967	0.00918
	(0.0501)	(0.0937)	(0.0286)
Dummy: female headed household = o,	-1.125**	-1.817	-0.729***
	(0.452)	(1.307)	(0.275)
Observations	8,619	8,619	8,619

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

Table 3 : Linking Weather Risk with Contract Choice: A Multinomial Logit Framework (2010)

VARIABLES	output share	output/input share	rental contract
rainfall coefficient of variation	2.502***	-13.82***	-3.970***
	(0.795)	(1.669)	(0.400)
Number of years possessed	-0.255***	-0.275***	-0.0593***
	(0.00957)	(0.0223)	(0.00310)
Dummy: soil quality lem	-0.648***	-0.292	-0.417***
	(0.193)	(0.424)	(0.108)
Dummy: soil quality lem-te	-0.443**	0.557	-0.628***
	(0.204)	(0.426)	(0.118)
Dummy: plot is irrigated	-0.342	-0.449	-0.600***
	(0.286)	(0.652)	(0.167)
Dummy: topography meda (flat)	0.320	-0.595	0.654***
	(0.384)	(0.532)	(0.243)
Dummy: topography dagetama (sloppy)	0.192	-0.922	-0.126
	(0.398)	(0.581)	(0.255)
Oxen days	-0.00172	0.0435***	0.0258***
	(0.00864)	(0.00895)	(0.00363)
Family labor	0.00573*	-0.00527	-0.00451***
	(0.00303)	(0.00523)	(0.00161)
Hired labor	-0.0113**	-0.000972	-0.00764***
	(0.00547)	(0.00791)	(0.00276)
Household size	0.0301	0.197***	0.166***
	(0.0239)	(0.0428)	(0.0134)
Dummy: female headed household	-1.321***	-0.153	-0.368**
	(0.337)	(0.510)	(0.145)
Dummy: head can read and write	-0.360***	-0.257	0.136**
	(0.119)	(0.243)	(0.0681)
Dummy: farming (family) is the primary activity of the head	0.0894	0.684	-0.308**
	(0.317)	(0.686)	(0.140)
Dummy: roof material of main house is corrugated metal	0.324**	0.195	0.136*
	(0.140)	(0.286)	(0.0782)
Number of rooms of main house	0.00586	-0.438***	-0.133***
	(0.0491)	(0.133)	(0.0332)
Dummy: female headed household = o,	0.238	1.917*	0.143
	(0.585)	(1.100)	(0.331)
Observations	7,740	7,740	7,740

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

The linear probability and logit models predict that a household is more than 20% more likely to adopt modern chemical fertilizers than under autarky. This effect goes down to 12.4% under the linear probability household fixed effects model, which controls for any time-invariant household characteristics. Since there are no moral hazard effects in both rental contracts and autarky, and we controlled for plot characteristics such as soil quality and the slope of the plot, this difference is likely from unobserved household characteristics.

Next we explore how contract choice influences the intensity of fertilizer use. The results from OLS, household fixed effects, and tobit random effects regressions are reported in Table 4. We run the tobit regressions because of left censoring in the dependent variable, fertilizer use per hectare. Three robust results emerge from these regressions: (1) there is significantly higher intensity of fertilizer use under fixed rental than any other contracts (by around 30 kg per hectare than under autarky); (2) there is no evidence that the intensity of fertilizer use under output-sharing contract and input-output is different than under autarky; (3) under all contracts, the value of household and farm assets positively influences the intensity of technology use. The last observation indicates that households either have to rely on their own financial resources or use their assets to obtain credit to access technology, suggesting potential credit market imperfections in the economy.[11] The estimates of the impact of a fixed rental contract on technology adoption (relative to autarky) from the tobit random effects and ordinary least squares regression are comparable (around 35.5 kg per hectare) and higher than under the fixed effects model (30 kg per hectare) which controls for unobserved time-invariant household characteristics. Other notable results from these

[11] In the perfect world, productions decisions should not be influenced by the household's level of wealth i.e. production decisions should be separate from consumption decisions or variables that exclusively affect consumption such as wealth.

regression include: (1) there is positive association between mean rainfall income at village level and the use chemical fertilizers, (2) farmers seem to apply fewer units of chemical fertilizer on plots with good soil quality, suggesting a possible substitution between soil quality and chemical fertilizers,[12] (3) households headed by illiterate farmers are less likely to use chemical fertilizers, and (4) the gender and age of the household head do not seem to have any significant impact on technology adoption. In addition, while we may expect that a household is more likely to rent in a more fertile piece of land, which, if not controlled, may bias the impact of rental contract on technology use, the bias appears to be negative. Finally, holding other factors constant, intergenerational or gender-biased transfer of land, if it exists, does not seem to affect technology use. Nevertheless, the validity of the results hinges on the assumption that we have controlled for all factors that influence the choice of contracts in these regressions. Therefore, we proceed to use inverse-probability weighted regression adjustment to control for selection into different types of contracts at household level.

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[12] This substitution is in essence between inputs that can potentially increase soil quality (like long term use of manure) and chemical fertilizers.

Table 4 – The Impact of Contract Choice on the Probability of Using Chemical Fertilizers

Variables	Linear Probability(LP)	Logit	LP Fixed Effects)
Wage contract	-0.130***	-0.163***	-0.0341**
	(0.0183)	(0.0252)	(0.0168)
Output sharing contract	0.00603	0.0128	0.0189*
	(0.0130)	(0.0161)	(0.0114)
Input-output sharing contract	0.138***	0.166***	0.119***
	(0.0267)	(0.0355)	(0.0242)
Rental contract	0.210***	0.265***	0.124***
	(0.0180)	(0.0250)	(0.0161)
Annual rainfall	0.000167***	0.000195***	9.70e-05***
	(1.25e-05)	(1.65e-05)	(1.64e-05)
Good soil quality	-0.0294**	-0.0378**	-0.0279**
	(0.0123)	(0.0156)	(0.0115)
Medium soil quality	0.00535	0.00703	-0.00576
	(0.0128)	(0.0164)	(0.0117)
Flat slope	0.0341	0.0471*	0.0240
	(0.0217)	(0.0286)	(0.0192)
Slightly slanted slope	-0.0239	-0.0308	0.0184
	(0.0226)	(0.0299)	(0.0200)
Value of farm and household assets in thousands of birr	0.00828***	0.0130***	0.00198**
	(0.000868)	(0.00138)	(0.000988)
Household head is illiterate	-0.0596***	-0.0716***	-0.0501***
	(0.00782)	(0.0102)	(0.0103)
Dummy for use of hired labor	0.159***	0.197***	0.122***
	(0.00900)	(0.0118)	(0.00840)
Female-headed household	0.0109	0.0120	-0.0150
	(0.0122)	(0.0157)	(0.0184)
Age of household head	0.000337	0.000343	-0.000456
	(0.000290)	(0.000380)	(0.000472)
Dummy for vegetables	0.0811***	0.156***	0.0385***
	(0.0147)	(0.0208)	(0.0133)
Dummy for fruits	-0.0826***	-0.0944***	-0.0844***
	(0.0218)	(0.0325)	(0.0192)
Dummy for spices	0.0577	0.0948*	0.0415
	(0.0413)	(0.0549)	(0.0350)
Dummy for tree c	-0.167***	-0.267***	-0.0994***
	(0.0116)	(0.0173)	(0.0111)
Dummy for oilseeds	-0.00685	0.00922	-0.0384**
	(0.0218)	(0.0321)	(0.0189)
Dummy for beans	0.0387***	0.0864***	0.00804
	(0.0104)	(0.0144)	(0.00917)
Dummy for cereals	0.441***	0.633***	0.394***
	(0.00975)	(0.0158)	(0.00882)
Constant	-0.175***		-0.0691*
	(0.0315)		(0.0385)
Observations	15,576	15,576	15,576
R-squared	0.241		

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 5 – The Impact of Contract Choice on the Intensity of Fertilizer Use (in kg/hectare)

Variables	(OLS)	(Fixed Effects)	(Tobit Random Effects)
Wage contract	-7.208	-7.638	-14.58***
	(10.46)	(6.567)	(4.762)
Output sharing contract	-0.310	-0.0752	2.349
	(6.024)	(4.628)	(3.202)
Input-output sharing contract	-0.179	1.006	14.33**
	(10.55)	(9.590)	(6.121)
Rental contract	35.13***	29.99***	35.50***
	(8.940)	(6.436)	(4.089)
Annual rainfall	0.0305	0.0267***	0.0272***
	(0.0184)	(0.00480)	(0.00312)
Good soil quality	-7.993	-6.296	-8.097***
	(9.486)	(4.433)	(3.022)
Medium soil quality	-1.409	-0.841	-0.368
	(7.606)	(4.604)	(3.171)
Flat slope	11.17	9.724	9.346*
	(8.748)	(7.715)	(5.495)
Slightly slanted slope	-0.277	1.538	-3.587
	(7.269)	(8.042)	(5.757)
Value of farm and household assets in thousands of birr	1.486**	1.207***	1.471***
	(0.604)	(0.332)	(0.205)
Household head is illiterate	-3.736	-3.929	-9.074***
	(4.759)	(3.019)	(1.962)
Dummy for use of hired labor	31.46***	29.21***	31.03***
	(7.081)	(3.233)	(2.159)
Female-headed household	-3.398	-3.629	0.159
	(4.906)	(4.711)	(3.051)
Age of household head	0.000453	0.000936	0.0408
	(0.163)	(0.114)	(0.0736)
Dummy for vegetables	3.213	1.893	25.42***
	(7.282)	(5.187)	(3.863)
Dummy for fruits	-19.08**	-17.54**	-14.71**
	(7.810)	(7.653)	(6.440)
Dummy for spices	-7.606	-7.604	12.80
	(8.222)	(14.44)	(10.19)
Dummy Tree crops	-31.17***	-29.22***	-50.64***
	(6.920)	(4.165)	(3.370)
Dummy for oilseeds	-23.40*	-22.99***	-10.96*
	(11.79)	(7.667)	(6.091)
Dummy for beans	-20.00***	-20.60***	1.312
	(5.701)	(3.669)	(2.658)
Dummy for cereals	45.24***	44.31***	100.5***
	(5.507)	(3.465)	(2.897)
Constant	-29.62	-25.95**	
	(22.14)	(11.64)	
Observations	15,576	15,576	15,576

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

B. Endogenous Contracts –Inverse-Probability Weighted Regression Adjustment

In this section, we control for selection into different contract types and estimate the average treatment effect of each contract type on the intensity of fertilizer use. This involves two steps. In the first stage we estimate a multinomial logit model to obtain the probability of adopting a specific type of contract type t, $p(x, j, \beta)$.

$$p(z, j, \beta) = \frac{\exp(x\beta_j)}{1 + \sum_{h=1}^{J} z\beta_h} \quad \text{and} \quad \beta' = (\beta'_1, \beta'_2, ..., \beta'_J),$$

where x represents household, plot, and village characteristics determine selection to specific contract type (j) and β_j represents the regression parameters in the multinomial logit model. The inverse-probability weighted regression adjustment uses weighted regression coefficients to estimate the average treatment effect. The weight of each plot (our unit of analysis), w_i in the treatment level (type) j is computed using the inverse probabilities of treatment as:

$$w_i(t) = \frac{j_i(j)}{p(x, j, \hat{\beta})} \left(\frac{j_i(j)}{p(x, j, \hat{\beta})} - 1 \right) \tag{17}$$

That is, the weight attached to a specific plot owned by a household with given characteristics is inversely proportional to the probability of selection in to a specific contract. The average treatment effects (ATE) of contract choice on technology use is defined as:

$$ATE_j = E(y_j - y_0) \; for \; t \in \{wage, rental, output - sharing, input - output \; sharing\}$$

where y_j is the potential outcome of intensity of technology use under contract j, and y_0 is the potential outcome of technology use under autarky. The average treatment effects estimated using inverse-probability weighted regression adjustment is presented in Table 6.

Accordingly, using autarky as control group, we find an average treatment effect of 34 kg per hectare for rental contract, slightly lower than the OLS and tobit random effects estimates we obtained earlier. Nevertheless, we do not find differences in the intensity of fertilizer use among other types of contracts.

Therefore, to link with the theory, the higher use of chemical fertilizers is mainly due to gains from trade rather than incentive effect i.e. the absence of moral hazard problem in rental contract. The lack of any significant difference in the intensity of use of technology between sharecropping contracts versus farmers who cultivate their farm using family labor also supports this argument.[13] Hence, the loss of potential output from weather risk is mainly due to the fact that efficient farmers who are more likely to use fertilizers are less likely to rent in land in the presence of insurance market imperfections.

Table 6 – The Impact of Contract Choice on Intensity of Fertilizer Use: Inverse-probability weighted regression adjustment ***(dependent variable is fertilizer use in kg/hectare)***

VARIABLES	Average Treatment Effect	Potential Outcome Mean
Output sharing vs. control group	4.926	
	(7.982)	
Input-Output Sharing vs. control group	9.660	
	(9.430)	
Rental contract vs. control group	34.45***	
	(8.538)	
Wage contract vs. control group	-6.659	
	(6.698)	
Autarky (Control group)		63.74***
		(6.580)

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

[13] If the tenant manages the farm under sharecropping contract, the results potentially mean that the gains from trade and incentive effects cancel each other, i.e., while under sharecropping land is potentially transferred to tenants who may be more likely to use fertilizer but the contract is plagued by moral hazard problems that discourage the use of chemical fertilizers.

4.2 Productivity Impact of Fertilizer Use : A Multinomial Endogenous Switching Regression Framework

Finally, to assess the impact of weather risk on agricultural productivity through its effect on the choice of agricultural technology, we estimate a production function allowing for the possibility of that contract choice is endogenous. To this effect we employ an endogenous switching regression framework which involves two steps : (1) estimate a multinomial logit model where household and plot characteristics along with weather risk determines the kind of contract the farmer chooses at the plot level (2) estimate a log-log production function for each contract regime controlling for probability of selection into the contract regime computed in the first stage .

Accordingly, we find that a one percent increase in fertilizer use increases yield by about 0.127% and 0.134% in own plots and plots under fixed rental contract, respectively. These comparable figures are consistent with economic theory as both contract types are free from moral hazard effects. This significant effect of fertilizer on yield is not surprising considering the results obtained in experimental farm trials in Kenya where using a quarter, half and one teaspoon of fertilizer is found to increase yield by 28%, 48%, and 63%, respectively (Duflo et al, 2008). We estimate magnitude of the impact of fertilizer on yield for plots under sharecropping contract to be around 4% but this effect is statistically insignificant.

The inclusion of household characteristics in the production functions deserve an explanation :while economic theory suggests that household characteristics should not influence production decisions when markets are perfect, we reject the null hypothesis that these household characteristics are jointly insignificant in production functions under all contract regimes suggesting the possibility that one or more markets are imperfect. This finding is important for the story we are telling since, as Stiglitz (1974) showed, the argument that sharecropping contracts help farmers pool risk only is tenable if there are other market imperfections[14]. The complete results from the second stage production function estimates controlling for selection into different contracts are presented in Table 7.

V. Conclusion

A significant portion of the population in most African countries, including Ethiopia, derives its livelihood from the agricultural sector, which is characterized by high volatility and very low productivity. Many economists view low adoption of chemical fertilizers and modern seeds as the primary cause for the stagnation observed in African agriculture. Thus, investigating the factors that explain the observed low adoption of modern agricultural technology by farmers in developing economies, particularly in Sub-Saharan Africa, has been the subject of extensive economic research in recent times (Duflo et al., 2009; Conley and Udry, 2010; Suri, 2011).

In this study, we argue that one of the most important channels through which climate change potentially affects the long-term standard of living and welfare in many agrarian economies is by influencing overall agricultural productivity and economy-wide structural transformation through its effect on farmers' choice of technology. In particular, we argued and provided empirical evidence that that an important channel through which weather risk influences the adoption of new agricultural technology is by altering the optimal land and labor contracts farmers choose which in turn, through their different risk-sharing and incentive mechanisms, influence both the probability of technology adoption and the intensity of its use that ultimately affect overall agricultural productivity.

[14] Otherwise, a farmer can potentially combine fixed and wage contracts to achieve risk-pooling as in sharecropping contracts.

Table 7 : Linking Technology Choice with Productivity: An Endogenous Switching Regression Framework

VARIABLES	own_cultivated plot	shared-in plot	rented-in plot
(log)Quantity fertilizer use	0.127***	0.043	0.134***
	(0.009)	(0.030)	(0.051)
(log)Quantity of manure use	0.034***	0.010	0.037
	(0.008)	(0.037)	(0.074)
(log)Quantity of pesticides	0.064***	-0.026	0.080
	(0.017)	(0.086)	(0.135)
rainfall in 2010(m)	-0.198***	-0.015	-0.314*
	(0.025)	(0.104)	(0.176)
(log) Family labor	0.339***	0.135	-0.209
	(0.040)	(0.109)	(0.200)
(log)Hired labor	0.049*	0.093	0.055
	(0.026)	(0.081)	(0.127)
(log)Oxen days	0.109***	0.274***	0.243*
	(0.023)	(0.087)	(0.131)
Dummy: soil quality lem	0.181***	0.492**	0.720*
	(0.053)	(0.205)	(0.393)
Dummy: soil quality lem-te	0.130**	0.083	0.690
	(0.055)	(0.244)	(0.435)
Dummy: plot is irrigated	0.132	0.034	-0.007
	(0.083)	(0.261)	(0.492)
Dummy: topography meda (flat)	0.064	0.158	-0.335
	(0.085)	(0.241)	(0.362)
Dummy: topography dagetama (slopy)	0.126	-0.002	-0.255
	(0.094)	(0.263)	(0.349)
(log)Value of household assets in birr	0.087***	-0.003	0.572
	(0.013)	(0.199)	(0.492)
Log(farm asset)	0.044**	-0.005	-0.240
	(0.020)	(0.119)	(0.421)
(log)Household size	0.099**	0.215	1.105
	(0.049)	(0.405)	(1.025)
Dummy: female headed household	-0.079	-0.077	1.228
	(0.065)	(0.478)	(1.388)
Dummy: head can read and write	0.060	0.100	-0.260
	(0.042)	(0.185)	(0.400)
Constant	5.154***	6.544***	-1.877
	(0.152)	(1.481)	(7.499)

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

Using panel data from Ethiopia, we present evidence linking weather risk, technology choice and agricultural productivity, and improve upon existing studies by identifying a specific mechanism (i.e., contract choice) through which climate change influences technology adoption and overall productivity. In particular, we find that in villages that characterized by long term rainfall variability and weather shocks, farmers are more likely to adopt sharecropping contracts, as opposed to fixed rental contracts, and both the probability of adopting chemical fertilizers and the intensity of fertilizer use is much lower under sharecropping contracts compared to rental contracts. Therefore, we argued that weather risk reduces the use of chemical fertilizers, thereby lowering overall agricultural productivity, by discouraging the transfer of land under rental contracts to more efficient farmers—resulting in a loss of the potential grains from trade—and by increasing farmers' propensity to use sharecropping contracts to cope with production risk — which are bedeviled by moral hazard problems.

The statistical evidence we present suggests that that in the absence of insurance markets, weather risk alters the optimal land and labor contracts farmers choose and this has implications on the adoption of modern technology and overall agricultural productivity. In fact, the potential loss of productivity due to a reduction in the use of chemical fertilizers because farmers resort to employ sharecropping arrangements to cope with weather risk can be thought of as the cost of adaptation to climate change. Hence, policies aimed at addressing insurance and credit market imperfections can potentially mitigate the adverse impacts climate change may have on agricultural productivity and overall structural transformation by preventing this loss of productivity , thereby effectively lowering the cost of adaptation to climate change, through the promotion rental market participation, which may result in the gains from trade and potentially eliminating the inefficiency associated with sharecropping contracts emanating from moral hazard problems.

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Table A1 Household Descriptive Statistics (2006)

	Total	High	Low	T-test
Household characteristics				
Household size	7.2047	7.1132	7.3563	0.260(0.0161**)
Number of dependents	6.9514	6.8045	7.2012	0.397(0.0002***)
Number of male adults	2.0229	1.9248	2.1913	0.260(0.000***)
Number of female adults	1.9091	1.8762	1.9675	0.090(0.0681*)
Female head dummy	0.1588	0.1512	0.1725	0.011(0.4704)
Head literate	0.4619	0.4696	0.4474	-0.015(0.4783)
Farming is head's primary activity	0.8686	0.8727	0.8612	-0.003(0.8136)
Dwelling has corrugated iron roof	0.6802	0.6751	0.6900	0.039(0.0503*)
Number of rooms in dwellings	2.2921	2.2505	2.3661	0.144(0.0096***)
Household age	51.1817	50.8643	51.7400	0.0723(0.2104)
Agricultural endowments				
Total value of livestock owned(birr)	4824.5235	4086.8960	6081.4413	1952.861(0.000***)
Value of bulls and oxen (birr)	4558.3914	3688.3602	6034.1837	2258.168(0.000***)
Value of other livestock (birr)	6838.1502	6051.1439	8188.0721	2345.84(0.0001***)
Number of bulls and oxen owned	1.6797	1.3946	2.1633	0.7756(0.000***)
Agricultural production				
Owned cultivated area (ha)	1.5920	1.3307	2.0661	0.680(0.000***)
Having owned cultivated land	0.9465	0.9339	0.9688	0.038(0.000***)
Area of sharecropped out land (ha)	0.1049	0.1103	0.0950	-0.134(0.5225)
Having sharecropped out land	0.1335	0.1343	0.1323	-0.003(0.9173)
Area of fixed rented out land (ha)	0.0353	0.0283	0.0483	0.0160(0.1705)
Having fixed rented out land	0.0836	0.0661	0.1149	0.044(0.0004***)
Area of sharecropped in land (ha)	0.1893	0.1856	0.1938	0.027(0.2451)
Having sharecropped in land	0.2424	0.2384	0.2484	0.031(0.1025)
Area of fixed rented in land (ha)	0.1059	0.0561	0.1967	0.131(0.000***)
Having fixed rented in land	0.1547	0.1111	0.2310	0.114(0.000***)
Assets and social capital				
Value of household assets (birr)	1707.4241	1540.0005	2000.9521	417.448(0.0082***)
House value (birr)	18400	16700	21500	4456.316(0.0030***)
Observations	2308	1476	832	

Table A2 Household Descriptive Statistics (2010)

	Total	High	Low	T-test
Household characteristics				
Household size	7.0935	7.0794	7.1166	0.0406(0.7109)
Number of dependents	6.9784	6.9395	7.0464	0.01024(0.3452)
Number of male adults	2.0188	1.9607	2.1258	0.1521(0.0082***)
Number of female adults	1.8793	1.8827	1.8742	-0.0076(0.8725)
Female head dummy	0.1541	0.1398	0.1801	0.0294(0.0664*)
Head literate	0.5082	0.0598	0.0560	0.0028(0.8996)
Farming is head's primary activity	0.9061	0.9060	0.9060	0.0039(0.7571)
Dwelling has corrugated iron roof	0.6651	0.6577	0.6781	0.0397(0.0517*)
Number of rooms in dwellings	2.4022	2.3967	2.4087	0.0304(0.6085)
Household age	50.3715	50.0575	50.9457	0.6856(0.2257)
Agricultural endowments				
Total value of livestock owned(birr)	4327.6828	3834.5615	5220.0535	1339.409(0.0000***)
Value of bulls and oxen (birr)	4033.3571	3412.0486	5157.8877	1656.232(0.0000***)
Value of other livestock (birr)	6130.5753	5848.9576	6644.2594	925.1852(0.1238)
Number of bulls and oxen owned	1.7873	1.5571	2.2019	0.6596(0.0000***)
Agricultural production				
Owned cultivated area (ha)	1.7136	1.5444	2.0189	0.435(0.0000***)
Having owned cultivated land	0.9676	0.9592	0.9828	0.0252(0.0002***)
Area of sharecropped out land (ha)	0.1146	0.1144	0.1152	-0.0023(0.9130)
Having sharecropped out land	0.1090	0.1100	0.1073	-0.0055(0.6830)
Area of fixed rented out land (ha)	0.0394	0.0328	0.0515	0.0152(0.1857)
Having fixed rented out land	0.0531	0.0473	0.0636	0.0151(0.1378)
Area of sharecropped in land (ha)	0.2499	0.2401	0.2483	0.236(0.3442)
Having sharecropped in land	0.2771	0.2746	0.2808	0.0243(0.2221)
Area of fixed rented in land (ha)	0.1209	0.0798	0.1859	0.1089(0.0000***)
Having fixed rented in land	0.1367	0.1078	0.1881	0.0855(0.0000***)
Assets and social capital				
Value of household assets (birr)	1415.5253	1325.8611	1579.7830	231.1547(0.0920*)
House value (birr)	16700	15000	19900	4356.892(0.0032***)
Observations	2303	1485	818	

Table A3 Plot Leve Descriptive Statistics (2006)

	Total	High	Low	T-test
Output and input use				
Crop output/ha (birr)	1509.1809	1606.7656	1401.0427	-206.333(0.1474)
Plot size (ha)	0.4766	0.4578	0.0576	0.050(0.0120**)
Used fertilizer	0.4048	0.3234	0.4773	0.154(0.000***)
Fertilizer used per ha (kg)	23.6484	17.4061	29.1866	11.785(0.000***)
Manure used	0.2075	0.2343	0.1810	-0.053(0.000***)
Manure used per ha (kg)	195.4114	250.8695	138.0806	111.988(0.004***
Used pesticides	0.2051	0.1510	0.2982	0.148(0.000***)
Pesticides used per ha (kg)	0.2051	15.7978	2.5883	1.608(0.0132**)
Pair of oxen days per ha	6.7916	5.5215	8.1470	2.622(0.000***)
Male family labor	26.0456	24.0626	28.6743	4.063(0.000***)
Female family labor	12.6002	10.6792	15.1509	4.465(0.000***)
Male hired labor	3.5373	3.4558	3.6545	0.198(0.4834)
Female hired labor	0.3904	0.3751	0.4359	0.061(0.3215)
Plot characteristics				
Years of possession	19.5629	19.3848	20.0002	0.6134(0.0122**)
Good soil quality	0.5685	0.5409	0.6221	0.081(0.0000***)
Medium soil quality	0.3089	0.3128	0.2914	-0.021(0.0228**)
Flat land	0.7651	0.7163	0.8570	0.140(0.000***)
Gently sloped land	0.2024	0.2458	0.1175	-0.0128(0.000***)
Irrigated land	0.0479	0.0558	0.0405	-0.015(0.0004***)
Crop choice				
Annual crops	0.7558	0.7244	0.7886	0.064(0.000***)
Permanent crops	0.1596	0.1900	0.1262	-0.064(0.000***)
Grazing land	0.0679	0.0697	0.0666	-0.003(0.5767)

Table A4 Plot Leve Descriptive Statistics (2010)

	Total	High	Low	T-test
Output and input use				
Crop output/ha (birr)	2937.9233	2471.2387	3688.5765	1008.849(0.0016***)
Plot size (ha)	0.5036	0.4593	0.5816	0.1048(0.0000***)
Used fertilizer	0.4420	0.3446	0.6210	0.292(0.0000***)
Fertilizer used per ha (kg)	26.0435	16.9737	42.6724	27.4936(0.0000***)
Manure used	0.2399	0.2805	0.1654	-0.121(0.0000***)
Manure used per ha (kg)	197.6208	243.7112	112.8660	-138.5521(0.0000***)
Used pesticides	0.2316	0.1595	0.3640	0.1684(0.0000***)
Pesticides used per ha (kg)	0.2693	0.2238	0.3529	0.0958(0.4055)
Pair of oxen days per ha	7.0672	5.8237	9.3269	3.2418(0.0000***)
Male family labor	21.9929	22.2252	21.5265	-0.7254(0.1983)
Female family labor	8.3820	8.4670	8.2209	-0.140(0.6255)
Male hired labor	4.1296	3.9428	4.4751	0.2453(0.4400)
Female hired labor	0.4650	0.4194	0.5491	0.094(0.2643)
Plot characteristics				
Years of possession	22.9961	23.1355	22.7488	-0.6083(0.0208*)
Good soil quality	0.6019	0.5630	0.6709	0.1156(0.0000***)
Medium soil quality	0.2997	0.3409	0.2266	-0.1160(0.0000***)
Flat land	0.6019	0.7184	0.8896	0.175(0.0000***)
Gently sloped land	0.2997	0.2557	0.0939	-0.1646(0.0000***)
Irrigated land	0.0479	0.0554	0.0347	-0.0237(0.0000***)
Crop choice				
Annual crops	0.7571	0.7205	0.8236	0.1038(0.0000***)
Permanent crops	0.1403	0.1661	0.0935	-0.7411(0.0000***)
Grazing land	0.0686	0.0777	0.0521	-0.0235(0.0000***)

Table A5 : Linking Weather Risk with Contract Choice: A Multinomial Logit Framework (2006)

VARIABLES	share-out	share-in	rent-out	rent-in
rainfall coefficient of variation	5.336***	0.725**	-3.703***	-2.160***
	(0.890)	(0.367)	(1.011)	(0.453)
Number of years possessed	-0.00382	-0.0806***	-0.0264***	-0.0802***
	(0.00580)	(0.00281)	(0.00658)	(0.00348)
Dummy: soil quality lem	-0.0896	-0.469***	0.0828	-0.429***
	(0.215)	(0.0875)	(0.247)	(0.112)
Dummy: soil quality lem-te	-0.0785	-0.182**	0.121	0.0902
	(0.231)	(0.0922)	(0.261)	(0.115)
Dummy: plot is irrigated	-0.0742	0.243**	-0.466	-0.239
	(0.324)	(0.124)	(0.424)	(0.173)
Dummy: topography meda (flat)	0.701	0.391***	-0.190	0.751***
	(0.518)	(0.150)	(0.316)	(0.202)
Dummy: topography dagetama (sloppy)	0.873*	0.231	-0.692*	0.279
	(0.528)	(0.158)	(0.358)	(0.213)
Oxen days	0.00918	-0.00676*	0.0235***	0.00708**
	(0.00786)	(0.00356)	(0.00535)	(0.00358)
Family labor	-0.0101***	-0.00247**	- 0.00826***	- 0.00377***
	(0.00249)	(0.00102)	(0.00223)	(0.00132)
Hired labor	0.0109***	0.00401**	0.00954***	0.00346
	(0.00293)	(0.00199)	(0.00302)	(0.00250)
Household size	-0.118***	0.0588***	0.0403	0.149***
	(0.0306)	(0.0123)	(0.0311)	(0.0148)
Dummy: female headed household	0.975***	-1.024***	-0.464	-0.245
	(0.186)	(0.145)	(0.290)	(0.156)
Dummy: head can read and write	-0.0547	0.0815	-0.460***	0.297***
	(0.154)	(0.0581)	(0.154)	(0.0731)
Dummy: farming (family) is the primary activity of the head	-0.0832	0.244*	-0.0415	-0.0647
	(0.203)	(0.142)	(0.300)	(0.157)
Dummy: roof material of main house is corrugated metal	0.385***	0.633***	-0.0741	0.385***
	(0.149)	(0.0648)	(0.158)	(0.0796)
Number of rooms of main house	-0.0102	0.0592**	-0.308***	0.0875***
	(0.0685)	(0.0267)	(0.0899)	(0.0317)
Dummy: female headed household = o,	-4.249***	-0.269	-0.572	-1.074***
	(0.669)	(0.254)	(0.604)	(0.315)

Table A6 : Linking Weather Risk with Contract Choice: A Multinomial Logit Framework (2010)

VARIABLES	share-out	share-in	rent-out	rent-in
rainfall coefficient of variation	16.74**	0.653	-8.794*	-2.818***
	(8.410)	(0.830)	(4.547)	(1.040)
Number of years possessed	-0.114**	-0.322***	-0.404***	-0.456***
	(0.0494)	(0.0117)	(0.0991)	(0.0217)
Dummy: soil quality lem	12.66	-0.640***	-2.510***	-0.323
	(959.2)	(0.220)	(0.937)	(0.277)
Dummy: soil quality lem-te	13.69	-0.319	-2.216**	-0.478
	(959.2)	(0.228)	(1.023)	(0.296)
Dummy: plot is irrigated	2.484***	-0.823***	-19.51	-1.127**
	(0.957)	(0.319)	(3,185)	(0.443)
Dummy: topography meda (flat)	13.26	0.567	17.01	1.064*
	(2,256)	(0.392)	(5,625)	(0.556)
Dummy: topography dagetama (sloppy)	-0.169	0.341	16.00	-0.0526
	(2,408)	(0.407)	(5,625)	(0.589)
Oxen days	0.0203	0.0112	-0.0221	0.0261***
	(0.0303)	(0.00703)	(0.0704)	(0.00835)
Family labor	0.0134	0.00269	0.00854	-0.00443
	(0.0232)	(0.00313)	(0.0222)	(0.00413)
Hired labor	-0.0480	-0.00782	-0.0809	-0.00493
	(0.0618)	(0.00533)	(0.0687)	(0.00563)
Household size	-0.116	0.0993***	-0.0603	0.208***
	(0.226)	(0.0260)	(0.148)	(0.0308)
Dummy: female headed household	0.260	-1.754***	-14.60	-0.821**
	(1.445)	(0.390)	(2,111)	(0.409)
Dummy: head can read and write	-0.967	-0.222*	-0.115	0.260
	(1.254)	(0.132)	(0.795)	(0.169)
Dummy: farming (family) is the primary activity of the head	-1.896	0.574	16.08	0.359
	(1.393)	(0.359)	(2,334)	(0.407)
Dummy: roof material of main house is corrugated metal	-0.563	0.455***	-2.317**	0.490**
	(1.012)	(0.155)	(0.924)	(0.199)
Number of rooms of main house	0.0191	-0.0225	0.305	-0.189**
	(0.154)	(0.0617)	(0.318)	(0.0829)
Dummy: female headed household	-33.98	0.0961	-29.34	0.0914

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