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Risk Implications of Farm Technology Adoption in the Ethiopian Highlands

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Abstract

In countries where insurance and credit markets are thin or missing, production and consumption risks play a critical role in the choice and use of production inputs and adoption of new farm technologies. In this paper, we investigated impacts of chemical fertilizer and soil and water conservation technologies adoption on production risks, using a moment-based approach and two years of cross-sectional data. A pseudo-fixed-effect model was estimated to generate first, second, and third moments of farm production. Our results revealed that fertilizer adoption reduces yield variability, but increases the risk of crop failure. However, adopting soil and water conservation technology has no impact on yield variability, but reduces the downside risk of crop failure. The results underscore that the risk implications of farm technology adoption vary by technology type. Furthermore, policies that promote adoption of fertilizers should be complemented by desirable instruments that hedge against downside risk. In that respect, if properly implemented, the safety net program and the weather insurance programs currently piloted in some parts of Ethiopia are actions in the right direction.

Key Words: production risks, farm technology, moment-based approach, Ethiopia

JEL Classification: C33, D21, Q16, Q24

Contents

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Introduction

In countries where insurance and credit markets are thin or missing, production and consumption risks play a critical role in the choice and use of production inputs and adoption of new farm technologies (Rosenzweig and Binswanger 1993; Moseley and Verschoor 2004; Dercon and Christiaensen 2007). Adoption of new farm technology could increase production risk either by increasing yield variability or increasing probabilities of crop failure. When investment decisions are constrained by lack of *ex post* coping mechanisms, such as both formal and informal insurance, risk will cause farmers to be less willing to undertake activities and investments that have higher expected outcomes, but also carry downside risks—yield variability and crop failure. Policy design based only on impacts on yield variability could potentially be misleading since a technology could reduce yield variability, but at the same time be subject to high risk of crop failure or drought. In such an environment, fully understanding these risks of farm technology adoption is of paramount importance in designing appropriate adoption and conservation policies and risk-hedging strategies.

Although different facets of the adoption literature have reported on the determinants of technology adoption, articles and studies on the risk implications of technology adoption are limited and suffer serious methodological and empirical deficiencies. Most studies that link production risk to technology adoption make implicit, if not explicit, assumptions about the effect of inputs on risk. (See, for example, the works of Stiglitz [1974], Batra [1974], and Bardhan [1977].) Most of these studies employed multiplicative stochastic specifications, which are restrictive in the sense that inputs that marginally reduce risk are not allowed. Naturally, this does not tally well with the observation that different inputs have different impacts on production

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risk and the notion that inputs are allocated by risk-averse farmers in line with their risk preferences. Although Just and Pope (1978) later proposed a more general specification that allows inputs to be either risk increasing or risk decreasing, it restricted the effects of inputs across higher order moments in exactly the way that traditional econometric models do across all moments (Antle 1983, 1987). The works of Leathers and Quiggin (1991) and Love and Buccola (1991, 1999) are somewhat applications of Just and Pope's specification in this regard.

In response to these restrictive approaches, Antle (1983, 1987) proposed a highly flexible approach under which standard econometric techniques can be used to identify the agricultural technology without imposing such arbitrary restrictions on inputs or farmers' utility functions. His moment-based approach begins with a general parameterization of the moments of the probability distribution of output and allows more flexible representations of output distributions. As such, this approach is ideally suited for analyzing the response of farmers to interventions when farmers face uncertainty and are averse to various moments of that risk—as in the Ethiopian highlands and other rural settings in sub-Saharan Africa. To the best of our knowledge, no empirical study has investigated the risk implications of farm technology adoption decisions using this more flexible moment-based approach in the context of developing countries. Notable exceptions are Koundouri et al. (2006) and Groom et al. (2008), whose studies were based on single cross-sectional data on irrigation in Greece and water-quota management in Cyprus, respectively. However, these studies suffered econometric problems where the unobserved heterogeneity that may influence technology adoption and production decisions and risk management strategies was not controlled for.

In light of this discussion, the objective of this paper is to provide empirical evidence on the risk implications of fertilizer and soil and water conservation technologies (hereafter called farm technology adoption) in the Ethiopian highlands, using Antle's flexible moment-based approach. The panel nature of the plot-level data collected in the Ethiopian highlands allowed us to control for unobservable characteristics that otherwise would bias the results and possibly lead to wrong conclusions.

The rest of the paper is organized as follows. In section 1, we present a brief account of the literature on farm technology adoption in Ethiopia. Section 2 outlines the underlying theoretical model of farmer behavior under risk and describes the empirical approach adopted in this study. The data from the Ethiopian highlands are described in section 3. Section 4 presents and discusses the econometric results, and section 5 concludes the paper.

1. Empirical Research on Production Risks and Farm Technology Adoption in Ethiopia

The Ethiopian government has put agriculture at the heart of its policies to generate economic growth and development. To achieve this objective, a development strategy known as Agricultural Development-Led Industrialization (ADLI) was launched in 1992–93. The strategy is based on agriculture as the primary stimulus to generate increased output, employment, and income, using land-management, or farm, technology (e.g., chemical fertilizer, soil and water conservation), improved seed, extension services, and credit facilities. Governmental and non-governmental institutions have invested substantial resources to promote land-management technology and extension and credit services, and to establish land management-related projects, such as soil and water conservation, fertilizer, and soil laboratories. Despite this, the agriculture sector is characterized by low external input use and low productivity, as well as high nutrient depletion and soil erosion that limit farmers' ability to increase agricultural production and reduce poverty and food insecurity

In the empirical literature, much has been written on the determinants of input and technology adoption in agriculture, with numerous intertwined issues—such as input availability, tenure security, information, education, and credit and other market constraints—receiving much attention. However, less has been documented of the differential ability of households to take on risky production technologies for fear of the welfare consequences if shock or introduction of new technology result in poor harvests and jeopardize households' future consumption. Using both theoretical and empirical models, Dercon and Christiaensen (2007) demonstrated how the possibility of low-consumption outcomes—when harvests fail—discourages the application of fertilizer by smallholder farmers in Ethiopia. Such risk aversion is especially of interest because it could lead to risk-induced path dependence and poverty traps (Yesuf and Bluffstone 2009, forthcoming).

Even if risk preferences are fundamentally the same, those who can insure their consumption against shocks take advantage of profitable, but risky, opportunities, while others may be limited to low-risk, low-return activities and lives of poverty (Eswaran and Kotwal 1990; Rosenzweig and Binswanger 1993; Mosley and Verschoor 2005; Dercon and Christiaensen 2007). Thus, understanding the risk implications of farm technology adoption is of significant importance when designing appropriate and effective policy interventions. Despite its critical role in designing appropriate policies and strategies, empirical studies in Ethiopia and other developing countries on the risk implications of technology adoption are almost non-existent. Exceptions are Rosegrant and Roumasset (1985) and Pandey (2004). Using a more restrictive specification of production function (i.e., multiplicative stochastic specification), both of these studies found that inorganic fertilizer is a risk-increasing input in the Philippines. Our paper extends the literature by investigating the risk implications of two important farm technologies in the Ethiopian highlands—chemical fertilizers and soil and water conservation—using a more flexible specification and moment-based estimation approach.

2. The Theoretical Framework and Empirical Approach

In this section,[1] following Antle's (1983, 1987) flexible moment approach and Groom et al.'s (2008) presentation, we develop a theoretical model of production function under risk to generate an empirical model to help us to analyze the risk implications of farm technology adoption in the Ethiopian highlands.

Suppose that the representative farm household problem (household *h*) is to maximize expected profit (if risk neutral) or expected utility (if risk averse) from the household's crop production from each plot (plot *p*) at time *t*. We assume that the agent is a price taker (both in input and output markets) and that climatic risk affects crop yield through the variable ε_{hpt}, whose distribution $G(.)$ is not affected by farmer actions. The fact that both input and output prices are non-random implies that ε is the only source of production risk.[2] Denoting *p* as a vector of output prices, $f(.)$ is the production function, $X^f{}_{hpt}$ is the fertilizer input of household *h* at plot *p* at time *t*, $X^c{}_{hpt}$ is the conservation effort, and $\boldsymbol{X^o}$ is the vector of other inputs; r^f is the per unit cost of fertilizer, r^c is the per unit cost of conservation efforts, and $\boldsymbol{r}$ is the corresponding vector of per unit prices of other inputs. Assuming that the production function $f(.)$ is continuous and twice differentiable, the representative risk-averse agent's problem would be given by:

$$Max_x E[U(\pi)] = Max_x \int [U(pf(\varepsilon_{hpt}, x^f_{hpt}, x^c_{hpt}, X^o) - r^f x^f_{hpt} - r^c x^c_{hpt} - r' X^o)] dG(\varepsilon_{hpt}), \quad (1)$$

where $U(.)$ is the Von Neuman-Morgenstern utility function. The first-order condition (FOC) for optimal use of the fertilizer input x^f_{hpt} associated with this problem would then become:[3]

[1] Detailed econometric discussions are presented in a separate paper; see Kassie et al. 2008.

[2] This assumption is not critical as long as farmers are price takers. Extending the model by allowing for price risk in addition to production risk, although feasible, would not bring about significant changes in the analysis.

[3] Subscripts are suppressed for ease of notation.

$$E\left[r^f \times U^{'}\right] = E\left[p\frac{\partial f(\varepsilon, x^f, x^c, X^o)}{\partial x^f} \times U^{'}\right] \Leftrightarrow E\left(\frac{\partial f(\varepsilon, x^f, x^c, X^o)}{\partial x^f}\right) + \frac{\text{cov}(U^{'}, \partial f(\varepsilon, x^f, x^c, X^o)/\partial x^f)}{E(U^{'})}, \quad (2)$$

where $U' = \partial U(\pi)/\partial\pi$. From equation (2), it is apparent that the shape of the utility function (whose curvature is increasing with the degree of absolute risk aversion) will determine the magnitude of the departure from the risk-neutrality case. For a risk-neutral farm household, the second term on the second element of equation (2) disappears and input-use decisions would be determined by the standard procedure of equating marginal values. When the producer is risk averse, the second term in the right-hand side of equation (2) is different from 0 and measures deviations from the risk-neutrality case. A similar procedure can be followed to derive the FOCs of conservation and other variables.

In principle, the optimal solution for element x^f (fertilizer input) would depend upon r^f, r^c, p, **r** and on the shape of functions $U(.)$, $f(.)$, and $G(.)$. This problem, however, is empirically difficult. In addition to the choice of technology specification, the distribution of ε needs to be known and the agent's preferences need to be specified.

For this reason, Antle (1983, 1987) proposed a flexible estimation approach that has the advantage of requiring only cross-sectional information on prices and input quantities. The key feature of this approach is that the solution to the producer problem can be written as a function of input levels alone. According to this approach and without loss of generality, maximizing the expected utility of profit with respect to any input is equivalent to maximizing a function of moments of the distribution of ε, those moments having themselves ***X*** as an argument. This is given by:

$$Max_x E[U(\pi)] = F\left[\mu_1(x^f, x^c, X^o), \mu_2(x^f, x^c, X^o), \ldots, \mu_m(x^f, x^c, X^o)\right] \quad (3)$$

where $\mu_j = (j = 1, 2, ..m)$ is the mth moment of farm profit, and $F(.)$ is a cumulative distribution function and completely unspecified. Using the FOC of this problem, the marginal impact of fertilizer input on the first moment is given by:

$$\frac{\partial \mu_1(x^f, x^c, x^o)}{\partial x^f} = \theta_{1f} + \theta_{2f}\frac{\partial \mu_2(x^f, x^c, X^o)}{\partial x^f} + \theta_{3f}\frac{\partial \mu_3(x^f, x^c, X^o)}{\partial x^f} + \ldots + \theta_{mf}\frac{\partial \mu_m(x^f, x^c, X^o)}{\partial x^f} + u_f \quad (4)$$

$$\theta_{jf}\ (j = 2, \ldots, m) = (-1)/j! \times (((\partial F(X))/(\partial \mu_j(X)))/((\partial F(X))/(\partial \mu_1(X)))),$$

and **X** is a vector of all inputs including fertilizer and conservation efforts, and u_f is the usual econometric error term. A similar procedure can be followed to derive the FOCs of conservation and other variables.

There are two salient features of this model. First, marginal contribution of an input to the first, second, or higher order moments is a linear combination of the marginal contributions of that input to the other moments (variance: $\partial \mu_2(X) / \partial X_k$, skewness: $(\partial \mu_3 (X)) / (\partial X_k, \ldots)$). Second, unlike the assumptions of a standard multiplicative production-function specification, which assumes that all inputs are risk increasing, this model presupposes that whether an input is risk increasing or risk decreasing is purely an empirical issue. A negative (positive) sign on the marginal contribution of an input to second moment indicates that the input is risk reducing (increasing), whereas a negative (positive) sign on the marginal contribution of an input to the third moment presumes that the input is downside-risk increasing (reducing).[4]

To account for market imperfections in the study sites for major inputs and outputs markets, we included plot and household characteristics in the specification.

In order to generate the three moments of farm revenue, we adopted the following procedure. First, the value of crop production per plot was regressed using observed and unobserved plot variables (including fertilizer and soil conservation variables) and household- and village-level variables to get an estimate of the mean effect. The estimated errors were then squared and regressed on the same set of explanatory variables to generate the second order moment (variance). Using the same procedure, we finally estimated the third moment or skewness (the estimated errors raised to the power of 3).

This procedure, however, is not free of econometric challenges. To obtain consistent estimates that revealed risk implications of technology adoption, we needed to control for unobserved heterogeneity that might be correlated with observed explanatory variables. The other potential problems are endogeneity bias due to the direct use of fertilizer-input and soil-conservation variables in the regressions which could possibly lead to inconsistent estimates.

One way to address these issues was to exploit the panel nature of our plot-level data and use household-specific fixed effects. The use of fixed effects techniques could also help us

[4] Note that θ_{3f} and θ_{3f} can be directly interpreted as Arrow-Pratt and downside-risk-aversion coefficients, respectively. See Antle (1983, 1987) and Groom et al. (2008) for details.

address the problem of household heterogeneity and endogeneity bias, if endogeneity bias is due to plot-invariant unobserved factors, such as household heterogeneity (Wooldridge 2002). However, if the source of the bias is plot heterogeneities, the use of household fixed effect, per se, would not remove the problem.

Controlling for plot heterogeneity is a bit more difficult than addressing household heterogeneity. Fortunately, our dataset offered a richer characterization of plot quality than that found in most of the other studies. In terms of plot characteristics, it included plot slope, plot size, soil fertility, soil depth, plot distance from the homestead, altitude, and input use. Including these variables in our model allowed us to minimize these biases. In order to reduce endogeneity bias due to the direct use of the input variables, such as fertilizer/manure, improved seed, conservation, and irrigation inputs, explanatory variables that we believed could govern these input use decisions were included in the regression. Finally, one can argue that crop choice is an endogenous decision. However, in our study villages, the cropping pattern was stable, where similar crops are grown year after year, based on crop rotation and preference of own product for household consumption. Thus, crop choices can be considered pre-determined variables in production function.

3. Data Sources and Types

The data used in this study[5] came from a farm survey conducted in 2002 and 2005 in the Amhara region of Ethiopia by the Environmental Economics Forum of Ethiopia, sponsored by the Swedish International Development and Cooperation Agency (Sida). All of the analyzed plots were located in the highlands at more than 1500 meters above sea level. Our dataset totaled 724 farm households in 12 *kebeles*,[6] and about 3369 plots, after removing missing observations for some variables and deleting those households with one plot observation to apply a fixed effects model. The mean plot altitude, which is closely associated with temperature and microclimate, was 2428 meters above sea level. In the sample, 50.4 and 32 percent of the sample plots had fertilizer and different conservation types, respectively.

Table 1 in the appendix presents descriptive statistics of the sample.

[5] A detailed description of the data is presented in Kassie et al. (2008).

[6] A *kebele* is a higher administrative unit than a village, usually made up of three or four villages, and is often translated as a "peasant association."

4. Results and Discussion

Table 2 presents the econometrics results for the mean, variance, and skewness functions. The moment estimation results revealed that most of the conventional inputs are important determinants of mean output (first moment). But, these inputs (except for fertilizer inputs) are not equally important in explaining second (variance) and third moment (skewness) estimates. The fact that the sign of the fertilizer inputs on the second moment is negative implies that fertilizers are risk reducing in the Ethiopian highlands—a finding in contrast to the implicit assumption of a multiplicative production function specification, which generally assumes that inputs are risk increasing. This also appears at odds with the empirical results of Just and Pope (1979), Rosegrant and Roumasset (1985), and Pandey (2004), which suggested that inorganic nitrogen fertilizer is a risk-increasing technology. However, a closer look at the negative sign of the fertilizer input on the third moment reveals that, although the fertilizer input reduces the yield variability, it indeed increases the risk of crop failure and hunger by pulling the skewness to the left.

This result has two important implications. First, designing policy using only the first two moments could be potentially misleading since an input could be risk (variance) reducing, but could also result in an increased downside risk, as in our case. Second, the fact that fertilizer adoption increases downside risk in the Ethiopian highlands implies that a policy design that propagates an increased use of fertilizer should be complemented by a strategy to ensure that farm households are covered for food production if that falls below a certain threshold.

Unlike fertilizer adoption, the risk implication of soil and water conservation adoption is weaker. Adopting conservation technologies in the Ethiopian highlands does not seem to have governing average yield (first moment) or yield variability (second moment). But, the positive and significant sign on the skewness function would suggest that adoption of conservation technologies reduces the downside risks of crop failure and hunger.

5. Conclusion

This paper, using a moment-based approach, empirically examines the risk implications of two types of farm technologies (fertilizer and soil and water conservation) in the Ethiopian highlands. We estimated a pseudo-fixed-effect model to generate first, second, and third moments of farm production. Based on two years of cross-sectional plot-level data, the econometrics results revealed that fertilizer adoption reduced yield variability, but increased the risk of crop failure. Adopting soil and water conservation technology had no impact on yield variability, but reduced the downside risk of crop failure.

This study has several important policy implications. First, unlike the conventional risk-increasing assumption of a multiplicative production function specification, the risk implications of farm technology adoption vary by technology type. For example, in the case of Ethiopian highlands, fertilizer adoption reduces yield variability, but increases downside risk; whereas soil conservation technology has no impact on yield variability, but reduces the downside risk of crop failure. Second, policies based on only the first two moments could be misleading. A production input could be risk-increasing in terms of yield variability. But, it could as well be risk-increasing in terms of enhancing the probability of crop failure or downside risk. Third, policies that promote adoption of fertilizers should be complemented by strategies that hedge against downside risk. In this respect, if properly implemented, the safety net program and the weather insurance programs currently piloted in some parts of Ethiopia are actions in the right direction.

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Appendix

Table 1. Summary Statistics of Variables

Variables	Mean (standard deviation)
Value of crop production per plot, in ETB*	501/873 (910.011)
Plot size, in hectares	0.344 (0.256)
Labor use per plot, in person days	43.754 (85.218)
Oxen use per plot, in oxen days	5.602 (5.230)
Fertilizer use per plot, in kgs	17.139 (25.619)
Seed use per plot, in kgs	31.614 (30.586)
Manure use per plot, in kgs	82.128 (273.928)
Residence distance to plot, in walking minutes	15.016 (17.515)
Plot altitude, in meters above seal level	2428.306 (131.090)
Residence distance to town, in walking minutes	62.418 (38.818)
Residence distance to road, in walking minutes	35.936 (30.597)
Household age, in years	48.494 (14.160)
Livestock holding, in tropical livestock units	4.418 (3.040)
Family size, in number of persons	6.452 (2.241)
Improved seed use, dummy	0.056
Gently sloped plots, dummy	0.655
Moderately sloped plots, dummy	0.286
Steeply sloped plots, dummy	0.059
Highly fertile plots, dummy	0.321

Moderately fertile plots, dummy	0.437
Poor fertile plots, dummy	0.242
Irrigated plots, dummy	0.277
Conserved plots, dummy	0.321
Rented-in plots, dummy	0.008
Number of plot observations	3399
Number of household observations	724

* ETB = Ethiopian birr

Table 2. Moment Estimates

Explanatory variables	Output value	Variance	Skewness
Ln(plot size), in hectares	0.239***	-0.006	-0.058
	(0.027)	(0.038)	(0.093)
Ln(labor use), in person days	0.120***	0.007	0.089
	(0.026)	(0.031)	(0.081)
Ln(oxen use), in oxen days	0.179***	0.001	0.031
	(0.026)	(0.028)	(0.062)
Ln(fertilizer use), in kgs	**0.005***	**0.002***	**0.003***
	(0.001)	(0.001)	(0.002)
Ln(seed use), in kgs	0.078***	0.008	0.011
	(0.020)	(0.023)	(0.054)
Manure use, dummy	0.033	-0.002	0.035
	(0.040)	(0.047)	(0.106)
Improved seed use, dummy	0.079	-0.121*	-0.174
	(0.058)	(0.067)	(0.140)
Moderately sloped plots, dummy	-0.010	0.054	0.119
	(0.030)	(0.039)	(0.113)
Steeply sloped plots	-0.029	0.065	0.025
	(0.060)	(0.055)	(0.102)
Medium fertile plots, dummy	0.025	-0.019	-0.070
	(0.032)	(0.046)	(0.148)
Poor fertile plots, dummy	-0.100***	0.009	0.010
	(0.036)	(0.044)	(0.117)
Irrigated plots, dummy	-0.077*	-0.024	0.074

	(0.047)	(0.049)	(0.097)
Conserved plots, dummy	**-0.049**	**0.053**	**0.174***
	(0.041)	(0.047)	(0.100)
Distance of plot to residence, in walking minutes	-0.000	0.001	0.002
	(0.001)	(0.001)	(0.002)
Plot altitude, in meters above sea level	-0.000***	-0.000**	-0.000
	(0.000)	(0.000)	(0.000)
Rented in plots, dummy	0.150	0.288	1.434
	(0.158)	(0.425)	(1.451)
Stalk crops, dummy	-0.243***	-0.018	0.018
	(0.049)	(0.064)	(0.153)
Pulse crops, dummy	-0.142***	-0.029	0.006
	(0.037)	(0.050)	(0.160)
Oilseed crops, dummy	-0.079	-0.064	-0.222
	(0.054)	(0.068)	(0.146)
Vegetable crops, dummy	0.016	0.097	-0.052
	(0.124)	(0.104)	(0.160)
Other crops, dummy	-0.622***	-0.012	-0.156
	(0.055)	(0.068)	(0.117)
Household head age	0.006	0.001	0.002
	(0.006)	(0.007)	(0.011)
Household livestock holdings, in tropical livestock units	0.022**	0.007	0.004
	(0.011)	(0.013)	(0.027)
Family size, in number of persons	0.005	0.006	-0.002
	(0.031)	(0.031)	(0.062)
Off-farm activity participation	0.065	0.076	0.152
	(0.049)	(0.063)	(0.150)
Year, dummy	-0.897***	0.005	0.078
	(0.046)	(0.046)	(0.086)
Constant	6.149***	0.976*	1.222
	(0.518)	(0.513)	(0.945)
R-squared	0.516	0.0126	0.0109
N	3399	3399	3399

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