AGRICULTURAL ECONOMICS

Agricultural Economics 44 (2013) 399–417

Productivity, credit, risk, and the demand for weather index insurance in smallholder agriculture in Ethiopia

Craig McIntosh[a,*], Alexander Sarris[b], Fotis Papadopoulos[b]

[a]*Graduate School of International Relations and Pacific Studies, University of California, San Diego, 9500 Gillman Drive, La Jolla, CA, 92093-0519*
[b]*Department of Economics, University of Athens, 8 Pesmazoglou St., Athens, 10559, Greece*

Received 1 December 2012; received in revised form 25 January 2013; accepted 22 February 2013

Abstract

The article explores the relationship between fertilizer use and the demand for weather index insurance (WII) among smallholder farmers in Ethiopia. We examine whether fertilizer use is profitable under current smallholder production conditions, whether risk-related factors affect fertilizer use, and we estimate the returns to inputs in the agricultural production function in the absence of insurance. We then study how these primitives of agricultural production functions relate to insurance demand. The study compares a survey-based estimate of willingness to pay with actual uptake for the weather insurance, finding the stated and actual demand to be almost completely uncorrelated. While those with high marginal returns to inputs say they would purchase insurance, only those with low marginal returns actually do, consistent with the stated purpose of the product as input insurance. Insurance demand proves to be highly responsive to the existence and amount of randomly allocated insurance vouchers.

JEL classifications: C83, G22, Q12

Keywords: Fertilizer; Weather index insurance; Ethiopia agriculture

1. Introduction and background

The purpose of this article is to explore the context and constraints to fertilizer use among smallholders in Ethiopia, and to examine how these factors relate to demand for weather index insurance (WII). We test whether fertilizer demand constraints pertain to risk, and assess whether WII can contribute toward increasing fertilizer usage. Agriculture remains the main source of income for most rural households in sub-Saharan Africa (SSA), and also the main occupation of almost all the rural smallholders. Hence increasing the productivity of agricultural production is a key aspect to rural poverty reduction. Given also the increasing scarcity of productive land in the Ethiopian context, increasing yields is the only way to enhance productivity. While there are many ways to increase agricultural productivity, fertilizer and other modern input use, along with adoption of improved varieties, have been identified as the major ways to do so.

The bulk of agricultural productivity increase in the world in the past few decades has been attributed to increased use of inorganic fertilizers. While SSA fertilizer use has also grown, the region still lags very much behind the rest of the developing world. Per hectare fertilizer consumption is less than one fifth of that of other developing countries (Heisey and Mwangi, 1996; Mellor et al., 1987; Morris et al.; 2007), and, while growing, the fact that it started at low levels (and that growth rates have been lower than those of other developing countries) has implied widening application and yield gaps. Most of the analyses of low fertilizer use in Africa concentrate on demand factors. Technical analyses have shown that the response of yields to fertilizer use in SSA is very high. For instance Heisey and Mwangi (1996) report that maize production in most African countries can increase by more than 10-fold per kilogram of applied fertilizer. Also profitability of fertilizer use appears to be very high in most SSA countries. For instance, Duflo et al. (2008) find that annualized rates of return to fertilizer use in Kenya, without complementary inputs are around 70%. Nevertheless, demand at farm level is very low. According to the extensive review by Morris et al. (2007) this is because "... incentives to use fertilizer are undermined by the low level and high variability of crop yields on the one hand and the high level of fertilizer prices relative to crop prices on the other. The demand depressing effects of unfavorable price incentives are aggravated by many

*Corresponding author. Tel.: 858 822-1125; fax: 858 534-3939. *E-mail address:* ctmcintosh@ucsd.edu (C. McIntosh).

 DOI: 10.1111/agec.12024

other factors, including the general lack of market information about the availability and cost of fertilizer, the inability of many farmers to raise the resources needed to purchase fertilizer, and the lack of knowledge on the part of many farmers about how to use fertilizer efficiently".

In addition to the driving role of risk, the absence of input credit is a key reason for the low use of improved inputs among African rural smallholders. Many studies have found that small farmers in developing countries are credit constrained, and as a consequence use few modern purchased inputs (for surveys of the extensive literature on rural credit markets and/or their absence in developing countries see Besley [1994] and Conning and Udry [2007] among many others). The absence of credit can come from the supply side as well as the demand side. On the supply side, banks may find it very risky and expensive to provide credit to rural smallholders, thus rationing the supply of credit or making available contracts that maybe too expensive or too demanding on collateral. On the demand side, apart from the situations where farmers may not have adequate collateral, even in situations where credit is available farmers may find it too risky to borrow (Boucher et al., 2008).

Recent years have seen analyses that pay particular attention to risk factors. Risk aversion is well accepted as a major factor in new technology adoption, such as improved seeds, but once adoption is made, risk aversion does not appear to reduce fertilizer application by more than 20% (Binswanger and Sillers, 1983, Roumasset et al., 1989). In addition to production risk, Dercon and Christiaensen (2011) recently showed that *ex ante* consumption risk could also affect fertilizer use. Similarly Lamb (2003) shows that risk avoidance in the face of incomplete insurance may be key in understanding limited fertilizer use.

Contrasting with studies showing high average returns to fertilizer, however, several recent studies emphasize the poor quality of soils that make adoption unprofitable (Marenya and Barrett, 2009), or the heterogeneity of farmer profitability of fertilizer use (Suri, 2011). The question of whether farmers are constrained from using fertilizer by risk and credit constraints, or by low returns, thus emerges as a key policy question. The former constraints can be ameliorated by financial service innovation, while if lack of uptake is driven by low returns then the poverty trap of low agricultural fertility may be much more fundamental.

A promising way to address un-hedged risk among smallholder farmers appears to be the expansion of WII. The interest in this specific financial service arises from the confluence of two ideas. First, while mutual insurance should make households in low-income countries well able to cope with idiosyncratic shocks, they are expected to be very vulnerable to covariate shocks (Townsend, 1994). For agricultural households this is likely to be a particularly important issue because agro-climatic shocks will be a primary driver behind temporal variability in consumption. This theoretical insight, combined with the lack of moral hazard in weather variation and the relative availability of rainfall and other meteorological data for developing countries (e.g., satellite-based NDVI), has led many to regard WII as a particularly promising welfare-enhancing intervention. If protection against risk can additionally unlock demand for risky productivity-enhancing inputs, WII holds the promise of first-order improvements in income for poor and risk-prone agricultural communities.

However, when WII products have been directly marketed to farming households in developing countries in pilot applications, uptake has typically been quite low (Cole et al., 2012), and insurance if anything appears to depress credit use (Gine and Yang, 2009). This dissonance between anticipated and actual demand raises a set of interesting questions concerning both the determinants of modern input use, as well as the willingness to pay (WTP; demand) for insurance. Several candidate explanations have emerged. First and most direct is the issue of basis risk; while actual farm-level yields may be driven by farm-level rainfall, the nearest rainfall station may measure a very imperfect correlate of this quantity. Furthermore, crops are subject to many perils other than rainfall (pests, hail, frost, theft, etc.). A product with high basis risk simply fails to achieve the desired goal of providing protection against correlated risks to consumption, and hence is not demanded for perfectly good reasons. More subtle explanations explored in recent years include the idea of "ambiguity aversion" (Bryan, 2010), under which households do not perfectly understand the distribution from which the relevant probabilities are drawn, and because they have a dislike of taking on contracts with uncertain properties their demand is limited. Another preference-related explanation is due to Clarke (2011), who suggests that in the presence of basis risk it is possible that households end up without payouts in the worst state of the world and yet still must pay premiums; hence highly risk-averse agents may dislike the product.

In this study we report first results from a pilot project aiming to utilize WII as a way to expand the supply of credit and consequently fertilizer demand by smallholders. The issues explored include whether fertilizer use is profitable under current smallholder production conditions, whether risk-related factors affect fertilizer use, whether there is *ex ante* demand for WII in such a context, and the purchase decisions ultimately made by farmers when they are offered such insurance. The project implemented a randomized control trial (RCT) experiment in the Amhara region of Ethiopia designed to explore whether the availability of WII interlinked with credit can expand the demand for fertilizer and thereby increase agricultural productivity. In this article we use the baseline data for the study to examine the constraints to agricultural productivity, we present the results of an *ex ante* stated WTP study, and we examine the actual uptake of insurance from the first year of the pilot.

There would appear to be two straightforward ways to test the empirical determinants of WTP for index insurance. The first and most logistically straightforward of these is simply to run a survey exercise where individuals are asked to provide a stated value for a variety of types of contracts. In order to comply with best practice, this type of study should be run as a contingent-valuation survey, and use randomized price levels to elicit WTP for each contract combination. The advantage of this approach is that it is direct and inexpensive, and does not require the considerable logistical feat of providing an index insurance product in the field. The disadvantage is the use of stated WTP values; quantities are estimated on the basis of answers to relatively complex hypothetical questions over unfamiliar financial products. The second possibility, of course, is to provide index insurance in a context of rich baseline data, and observe the determinants of the actual sales. This latter method is clearly preferable in terms of the credibility of the results, but is considerably more complex. In this study we implement both methods, and compare the results obtained from each.

We first use observational data on input use and plot-level yields to explore the constraints to fertilizer use, as well as the likely profitability of increased use. We show that households in the region of the project are constrained on the credit side, and also utilize low quantities of improved inputs. We then explore the profitability of additional input use by estimating the marginal products of labor, land, and capital, and comparing them to market values. We supplement this with an analysis of the demand for fertilizer. Subsequently we provide some simple summary statistics on the *ex ante* stated WTP for index insurance, designed to protect farmers from losing their investment in modern input use. Next, we validate actual demand against this stated measure, and find them to be very poorly correlated, indicating that stated WTP would have provided a very poor proxy for actual demand. Finally, we examine the determinants of actual uptake for the 460 research subjects who were members of treatment cooperatives in which at least one contract was sold. We find insurance uptake to be driven very strongly by price discount vouchers, and that households who were using the most chemical fertilizer have the highest demand for WII.

2. The Ethiopian context

Agriculture is the main productive sector of the Ethiopian economy. It accounts for a little under 50% of the gross domestic product, provides employment for 80% of the population, generates about 90% of the export earnings, and supplies about 70% of the country's raw material to secondary activities. Crop production is estimated to contribute on average around 60%, livestock accounts for around 27%, and forestry and other subsectors around 13% of the total agricultural value. Over 95% of the cultivated land is under smallholder peasant agriculture. Low input use, and degradation of the natural resources resulting from the cumulative impact of the actions of these small land users has resulted in the exposure of smallholders to food insecurity and generally, limited agricultural growth. Any prospects of growth in Ethiopia, especially of the pro-poor nature, must deal with improving smallholder farm productivity. The Government of Ethiopia (GOE) has adopted an Agricultural Development-Led Industrialization (ADLI) strategy, focusing first on output growth in agriculture through technologies such as fertilizer, seeds, and infrastructure, and focusing especially in cereals. Dercon and Hill (2009) have suggested that the technical aspects of this strategy need to be complemented by policies to make it attractive to farmers to adopt new practices and improved seeds.

Most of Ethiopian agricultural production takes place under rain-fed conditions and is subject to considerable weather variations. Furthermore, the use of improved inputs, such as fertilizer and improved seeds is very low. The overwhelming reason for low use of modern inputs is that they are considered too expensive or that there is lack of cash. The high cost of credit adds to the cost of fertilizer. According to the Ethiopian Rural Household Survey 1994-1999 (ERHS), in 1999 71% of those purchasing fertilizer used formal seasonal credit provided via parastatals, and the implicit median interest rate was calculated at 57% (Dercon and Christiaensen, 2011). However, as Dercon and Christiaensen showed, fertilizer use, while profitable, is risky. They showed that the lack of insurance against the risks faced leads to low input use and inefficient production choices. These results provide the motivation for the pilot project reported in this article.

Fertilizer use in Ethiopia has remained low despite efforts by the government to promote its adoption through improved extension services and access to credit. Dercon and Hill (2009) report that fertilizer application in terms of quintals per hectare of fertilized area has not increased between 1997/1998 and 2007/2008, despite the apparent doubling of total fertilizer sales during the same period, which can be partly explained by expansion in cultivated area.

A host of demand and supply side factors have been invoked to explain the limited adoption of fertilizer in Ethiopia including limited knowledge and education (Asfaw and Admassie, 2004; Yu et al., 2011), risk preferences, credit constraints (Croppenstedt et al., 2003), irregular rainfall (Alem et al., 2008), limited profitability of fertilizer use (Dadi et al., 2004; World Bank, 2006), lack of market access (Abrar et al., 2004), incomplete markets (Zerfu and Larson, 2010), inefficiency of input use (Yu et al., 2011), as well as limited or untimely availability of the inputs themselves.

The system of fertilizer and other input distribution and sales in Ethiopia has evolved over time, and has been changing constantly since the mid 1990s. By the mid 1990s, and after the lifting of the state monopoly on the fertilizer distribution under the Derg regime, about 67 wholesalers and around 2,300 retailers handled fertilizer distribution and sales (World Bank, 2006). By 2004 few private companies and a public enterprise, the Agricultural Input Supply Enterprise (AISE) dominated the wholesale market. In recent years, as it applies in the region of study (Amhara), the Cooperative Unions (CUs) handle the wholesale function by ordering supplies through the AISE (financed by the publicly owned Commercial Bank of Ethiopia [CBE]), on the basis of potential demands transmitted to them about 10 months before the actual application time by the primary cooperatives, who collect and aggregate the individual farmers' desired purchases considerably before the production period.

Timely and adequate supply of fertilizer is one of the major problems reported by a significant proportion of the households surveyed in 2004 by the Ethiopian Economic Association according to a World Bank survey mentioned by Zerfu and Larson (2010). More than 70% of the households reported that fertilizer is often supplied late and around 40% of the households reported that supplies were inadequate. The survey results also pointed to high fertilizer price and tight credit repayment schedules as problems that constrain fertilizer use. Our own fieldwork indicated that credit is provided to eligible farmers largely on the basis of need and not ability to pay, and is typically guaranteed by the regional governments. Recently the GOE has decided to move to a system whereby farmers can purchase fertilizer only on cash. This, of course, is likely to make the demand for fertilizer much more dependent on available cash flow to the farmers at the time the purchases are made or fertilizer is needed.

The analysis done for this article is part of a larger project designed to pilot the use of WII as a collateral substitute for production credit for rural smallholders in Ethiopia. Given the extensive weather risks faced by rural smallholders in Ethiopia, and the complete absence of private agricultural production credit, a variety of weather insurance pilots have been implemented in recent years across Ethiopia in order to assess whether such products can improve the lot of farmers. All previous projects, however, have tried to pilot index insurance as a safety net rather than as an incentive to productivity improvements. The Ethiopian Project on Interlinking Insurance with Credit in Agriculture (EPIICA) works with the largest private bank in Ethiopia (Dashen Bank) and the largest private insurance company, Nyala Insurance Company (NISCO), and targets a high potential production region (Amhara) where it is presumed that risk and credit are major constraints to expanding production. NISCO is the first private insurance company in Ethiopia to pilot WII products.

The idea of the project is to test whether providing the private bank with WII on its loans can release credit resources for production by smallholders, and whether smallholders are willing to pay for the combined cost of credit and insurance. EPIICA is piloting the sale of WII tied with short-term production credit. To that end, a baseline survey was conducted in early 2011 in 120 rural Kebeles (villages or farmer associations) in four zones of the Amhara region in Ethiopia.[1] The choice of the Kebeles was nonrandom but instead was designed on the basis of informed opinion of NISCO as to where in the Amhara region the market for WII has best potential. Households within the selected kebeles were randomly sampled to participate in the study; in each village 18 cooperative households and 2 households that are not a member of the primary cooperative were selected. Because fertilizers are procured exclusively through primary cooperatives and their upper level zonal CUs in Ethiopia, it is anticipated that cooperative households may display a higher propensity to uptake additional fertilizer if risk concerns can be ameliorated.

[1] The zones are North Shewa, West Gojam, South Wello, and North Wello.

The assumptions on which the project is based are the following: First, from a production possibility perspective, it is assumed that there is considerable unrealized potential. Field visits to the zones by the project team suggested that fertilizer usage resulted in large increases in yields on farmer plots (local extension agents report two- to threefold yield increases in good years from the use of improved inputs).

The second assumption relates to the absence of rural productive credit markets. Ethiopia is a country where rural credit markets for agricultural productive working capital are almost totally absent save for the inputs provided on credit by the cooperatives and guaranteed by the government through advances by the government-owned CBE. The assessment from early field visits suggests that there is currently a great unmet need for expanding credit for agricultural production. The stated intent of the GOE to move to a cash-only basis for fertilizer purchases in the upcoming years suggests some urgency in the quest to identify alternate sources and modalities for input credit to replace the previous government-backed system.

The major constraint on the demand side of the credit issue seems to be the risk that farmers face when unable to repay from reduced current production. Many farmers in recent years had to sell assets to pay previous government-guaranteed agricultural debts, and this seems to discourage them from wanting uninsured credit. In short many farmers seem to be risk rationed in the terminology of Boucher et al. (2008). This risk arises because the incentive constraints against morally hazardous behavior require the lender to leave substantial risk on the borrower, and if a sufficient component of that risk is outside the control of the borrower, then profitable loan contracts may be refused by borrowers. Demand for both credit and insurance may be further depressed by ambiguity over the potential outcomes (Bryan, 2010).

The link between the provision of insurance and fertilizer uptake has been examined recently by Hill and Viceisza (2009) in an experimental setting in Ethiopia. They studied how smallholders' decisions to purchase fertilizer would be affected by the availability of insurance. They found some evidence that fertilizer purchases were positively affected by the availability of insurance. Their experimental design, however, did not consider the issue of whether or not the availability of credit would influence the uptake of fertilizer.

3. Structure of households and production constraints

Table 1 exhibits some basic demographic and agronomic information from our 2011 rural household survey,[2] while Table 2 exhibits information about the average incomes of the households surveyed. It can be seen that 47% of household heads have no education, and only 23% have any formal education (with an average of only 4.7 years); 53% of household

[2] The survey was conducted in February–March 2011, and most of the information referred to year 2010.

Table 1
General demographic and agronomic information of the rural households surveyed in Amhara in 2011

	All	North Shewa	West Gojam	South Wello	North Wello
Number of households	2,399	1,199	480	360	360
Average household size	5.3	5.5	5.7	4.6	4.8
Average age of the head (years)	49.7	51.4	46.3	49.6	48.7
Sex of household head (%)					
Male	89.4	89.2	92.7	87.2	88.1
Female	10.6	10.8	7.3	12.8	11.9
Type of household head's education					
No education	46.7	37.3	62.1	48.6	56.0
Formal education	22.9	23.6	16.0	26.0	26.5
Informal education	30.5	39.1	21.9	25.4	17.5
Duration of household head's formal education (years)	4.7	5.0	4.6	5.0	3.9
Average land owned per household (ha)	1.28	1.42	1.47	1.00	0.83
Average land cultivated in the past 12 months (ha)	1.38	1.54	1.63	0.89	1.01
Average number of parcels per household	4.03	4.18	4.53	3.49	3.42
Percent of area irrigated	11.1	11.9	5.3	6.7	20.6

Sources: Authors' calculations from EPIICA 2011 survey.

Table 2
Level and structure of incomes of surveyed households

	All	North Shewa	West Gojam	South Wello	North Wello
	Birr per year*				
Total income per capita	1,770	1,836	1,873	1,925	1,255
Total cash income per capita	1,060	1,095	1,093	1,194	751
Total noncash income per capita	711	742	781	722	505
	Percentage of total incomes				
Total cash income per capita	59.9	59.6	58.4	62.0	59.8
Total noncash income per capita	40.2	40.4	41.7	37.5	40.2
Nonfarm income					
Nonfarm cash income per capita	12.3	11.9	6.8	14.8	21.8
Nonfarm in kind income per capita	1.4	0.4	0.1	1.7	8.0
Crop income					
Cash crop income per capita	29.1	28.3	35.4	32.4	15.4
Crop in kind income per capita	25.2	21.7	33.8	25.5	24.7
Livestock income					
Livestock cash income per capita	18.5	19.5	16.2	14.9	22.7
Livestock in kind income per capita	13.6	18.2	7.7	10.3	7.5

*In 2010 (the year to which the survey information referred to) 1 US dollar was equal to about 13.3 birr.
Sources: Authors' calculations from EPIICA 2011 survey.

heads cannot read or write. Land owned and cultivated is very small, and split in several parcels. Average income per capita is around 130 USD of which 40% is noncash income. Of total income only 13.7% is nonfarm income, 54% is crop income, and 32% is livestock income. Almost 70% of households state that they have not enough, or just enough, income to cover food needs, and only 8.2% state that their income is adequate to cover all their needs. Clearly most of the households in the sample are quite poor, despite the intention to pilot the project in areas thought to be better off and with higher agricultural potential.

Table 3 illustrates use of agricultural inputs. The fraction of households that use *any* chemical fertilizer turns out to be relatively high, with more than 50% of households using at least some of it. On the other hand only 30% of farmers use improved seeds, with the share dropping to 7.6% in North Wello. Interestingly the average amounts spent on purchasing chemical fertilizers are quite high given the incomes of households. It is seen in Table 2 that the average per capita cash income of the households of the sample is 1,060 birr, half of which is crop cash income. Multiplied by the average household size of 5.3, this translates into an average total household cash income of 5,618 birr per annum, of which half is cash income from crop sales. Compared to this the average expenditure on chemical fertilizer per household (both diammonium phosphate [DAP] and Urea) is from Table 3 equal to 1,687 birr or 30% of total cash income or 60% of total crop cash income. While this is a large share, it does not exhaust the total cash expenditures for all inputs (which include inputs on livestock and other general inputs), which (not shown in Table 3) amount to 3,468 per household, or 62% of total cash income and more than 100%

Table 3
Use and spending on farm inputs

	All	North Shewa	West Gojam	South Wello	North Wello
Percent of households using:					
Improved seeds	29.9	21.6	84.6	6.0	7.6
Organic fertilizers	58.5	55.7	53.1	73.6	60.2
Chemical fertilizers (Urea)	55.4	58.7	95.2	13.6	31.9
Chemical fertilizers (DAP)	53.0	56.6	94.6	12.8	24.9
Chemicals (insecticides herbicides)	29.3	38.4	43.0	3.7	6.2
Average value of purchased inputs per household (birr)					
Improved seeds	327	731	161	114	163
Organic fertilizers	78	159	0	88	3
Chemical fertilizers (Urea)	704	885	629	126	158
Chemical fertilizers (DAP)	983	1140	997	143	154
Chemicals (insecticides herbicides)	213	122	436	26	51
Quantity of inorganic fertilizer used (kg/ha)					
Urea inorganic fertilizer	41.9	52.1	65.2	6.0	12.8
DAP inorganic fertilizer	47.3	53.7	91.4	6.0	8.4
Total inorganic fertilizer	89.2	105.8	156.6	12.0	21.2
Percent of households who used credit for:					
Improved seeds	10.5	14.2	9.2	0.0	10.5
Chemical fertilizers (Urea)	28.8	35.4	27.0	6.3	6.2
Chemical fertilizers (DAP)	26.4	32.6	23.4	4.4	6.8
Chemicals (insecticides herbicides)	2.8	3.9	1.5	0.0	13.6

Sources: Authors' calculations from EPIICA 2011 survey.

of crop cash income. It thus appears that it may not be easy for households to allocate more cash to any input, including fertilizer, without access to loans.

According to data in Dercon and Hill (2009), the average national fertilizer application rate in 2007/2008 was 116 kg per fertilized hectare. Alem et al. (2008) report that in the highlands of Ethiopia in 2007 the application rate at farm level is 89.8 kg/ha, while at plot level the rate is much higher at 348.8 kg/ha. This must be compared to the recommended application rates, which are 100 kg of Urea and 100 kg of DAP (or 200 kg total inorganic fertilizer per hectare) for the highlands of Ethiopia. The figures reported in Table 3 suggest inorganic fertilizer use, which is smaller than what is reported by Dercon and Hill (2009), but the same as what is reported by Alem et al. (2008) for the Ethiopian highlands. The use appears to be higher in North Shewa and West Gojam, where in fact the average fertilizer application rate appears to be not much lower than the recommended rate. However, use is much lower in South and North Wello.

The final rows of the table highlight the fact that few households receive credit for inputs. In North Shewa and West Gojam about one third of households receive credit for fertilizer, but this proportion is less than 10% in South and North Wello. On average only 15% of all households received credit for fertilizer, improved seeds, or pesticides. However, about half of the households indicated that they would have wanted to use more of the relevant modern input, and almost all of them indicated that the reason they could not use more of the input was unavailability of own funds or credit. These observations suggest that farmers are not using the amounts of inputs they want.

We now turn to the uses of finance and to credit constraints. Table 4 exhibits various indicators of financial market use among the EPIICA smallholders. It seems that the level and depth of financial services is rather small. Only 20.9% of households have a member who belongs to a microfinance institution (MFI), 17.4% of households have a member with a bank account, 14.6% have a member who took a nonfarm loan in the year before the survey, and only 22% applied for a loan to a bank or MFI in the past five years. On the other hand 16.8% needed an emergency loan in the year before the survey. Concerning loans for agricultural inputs, 70% of those who obtained any loans for inputs obtained them from primary cooperatives, about 8% from private traders and companies, 15% from MFIs, and the remainder from family, friends, and others.

4. Profitability and efficiency of input use

In this section we explore the efficiency of input use in crop production that will be utilized in later estimations. To analyze this, we first fit a standard Cobb–Douglas production function for the gross value of crop output, using instrumental variables for the endogenously determined right-hand variables. We introduce a variety of potential productivity determining variables in the right-hand side in order to explore the determinants of total factor productivity (TFP). The details of the analysis and estimations are shown in the Appendix.

To explore allocative efficiency, we use the estimated production function to calculate the value of marginal product of factor k (VMP_k) for each farmer, as in Lerman and Grazhdaninova (2005) and Carter and Wiebe (1990).

Table 4
Finance and credit

	All	North Shewa	West Gojam	South Wello	North Wello
Percent of households with at least a member belonging to a MFI formed group	20.9	32.1	9.7	23.9	21.9
Percent of households with at least a member having a bank account	17.4	13.8	12.3	20.0	16.3
Percent of households with at least a member having taken a loan over the past year (for nonagricultural purposes)	14.6	19.4	6.4	20.6	15.2
Percent of households that applied over the past five years for a bank or an MFI loan (for nonagricultural purposes)	22.0	24.6	17.4	44.2	25.2
Percent of households that over the past year needed money quickly for an emergency that they could not cover from own resources	16.8	21.5	10.3	47.5	21.3

Sources: Authors' calculations from data in EPIICA 2011 survey.

Allocative efficiency is determined by comparing the value of marginal product of factor X_k (VMP_k) with the marginal factor cost (MFC_k). We assume that farmers are price takers in input markets, so that the price of factor X_k (P_k) approximates MFC_k. If $VMP_k > MFC_k$, factor k is underused, and farm profits or efficiency can be raised by increasing the use of this factor. If, conversely, $VMP_k < MFC_k$, the input is overused and to raise farm profits its use should be reduced. The point of allocative efficiency (and maximum profit or minimum cost) is reached when $VMP_k = MFC_k$.

For land the marginal product computed from the production function is compared to the value added per hectare estimated from the current production pattern. It would have been more appropriate to use land rental values, or land sales prices multiplied by some discount rate, but there are no rentals reported in the survey, and very few land sales reported. For labor the marginal product is compared to the direct observations from each household concerning the wage rates they pay for hired labor (both in cash and in kind). For intermediate inputs, the marginal products must be compared to 1, as the variables used for inputs are expressed in ‘000 Birr, and so is output. Concerning capital, the variables for capital and output are expressed in ‘000 Birr. We neither have rental values of capital, nor local interest rates. Nevertheless, if the discount rate is smaller than 1, the VMP of capital should be compared to a value smaller than 1. We utilize a value of 20% for the comparisons in the tables.

Table 5 reports the averages of these marginal products and compares them with the average market values. It seems that land is utilized at higher than optimum levels, as the average marginal product is smaller than the value added per hectare. For purchased inputs, the average marginal product is 4.5, which is far above the "market" value of 1. This implies that inputs are used at levels much below their optimal values. The same holds for agricultural capital. On the other hand, the average marginal product of family labor on their farm is less than half of the market price of labor, suggesting considerable excess labor in farms. All of these observations are consistent with a farm structure composed of undercapitalized and labor surplus farms, with land having being allocated inefficiently. From our perspective the important thing to note is that there seems to be considerable scope for using additional intermediate inputs.

Table 5
Marginal products of production factors compared to market prices of the factors (means across surveyed households)

	Unit	All
Marginal product of land	‘000 Birr/Ha	2.8***
Value added crop prod./ha	’000 Birr/Ha	11.9
Marginal product of purchased inputs (compared to 1)		4.5***
Marginal product of labor	Birr/month/man	484***
Market price of labor	Birr/month/man	1,176
Marginal product of capital (Compared to 0.2)		1.7***

***Statistically different from actual or estimated market price (in italics) at the 1% level.
Sources: Authors' calculations from data in EPIICA 2011 survey.

5. The demand for fertilizer

In this section we present an analysis of the survey data concerning the demand for fertilizer. We utilize information on total expenditures on inorganic fertilizer. There are many households who exhibit zero fertilizer purchases. Hence the estimation of the various factors determining the demand for fertilizer must follow a two-step procedure, with the first step analyzing factors that determine the decision to purchase the input, while the second stage analyzing the demand factors given the decision to purchase or use. For the econometric analysis we utilize the standard Heckman two-step procedure. Other authors analyzing the same issue, such as Yu et al. (2011) and Zerfu and Larson (2010) also utilize two-step procedures, albeit of a different nature.

Table 6 exhibits the results of the linear Heckman corrected regression. Larger cultivated area and larger household size imply a higher probability of purchasing fertilizer. Similarly

Table 6
Determinants of purchased inorganic fertilizer

Dependent variable: log value of purchased inorganic fertilizer	Heckman's two- step consistent estimator	First stage estimations
Log acres of land cultivated	0.258***	0.394***
	(0.093)	(0.055)
Log value of agricultural capital	0.182***	-0.007
	(0.051)	(0.040)
Log household size in equivalent adults	−0.060	0.249***
	(0.110)	(0.081)
Dummy = 1 if anyone in the household had operated an income generated enterprise over the past 12 months	−0.124	0.204**
	(0.140)	(0.098)
Share of wages to total household income	0.042	−0.069
	(0.290)	(0.217)
Share of nonwages – nonfarm income to total household income	0.437	−1.265***
	(0.318)	(0.179)
No. of big animals (oxen & cows) over the previous year	−0.036**	0.064***
	(0.018)	(0.015)
Average area irrigated	−1.268***	0.655***
	(0.172)	(0.121)
Average rain in past 12 months (meaning 1 better, 3 worse than normal)	−0.100*	−0.138***
	(0.056)	(0.040)
Lamda	−1.581***	
	(0.198)	
Log age of household head		−0.458***
		(0.110)
Education of head of household in years (formal)		0.029**
		(0.014)
Dependency ratio		0.085
		(0.147)
Risk averse household head		−0.350**
		(0.142)
Head or anyone else in the household member of a cooperative		0.144
		(0.101)
Trust in the kebele cooperative		0.010
		(0.065)
Quantity credit constrained		−0.251***
		(0.083)
Price credit constrained		−0.025
		(0.123)
Risk credit constrained		−0.275***
		(0.083)
Average slope of land (1 meaning all steeply sloped, and 3 all flat land)		0.455***
		(0.067)
Average way farm is cultivated (meaning 1 by hand, 3 by tractor)		0.347*
		(0.211)
Average altitude of land cultivated (meaning 1 much above compared to village center and 5 much below compared to village center)		−0.051
		(0.041)
Experienced shock: drought		−0.369***
		(0.071)
Constant	6.980***	0.043
	(0.374)	(0.696)
Observations	2,217	
Censored observations	892	
Uncensored observations	1,325	
Wald Chi^2	111.93	
Prob > Chi^2	0.0000	

Standard errors shown below point estimates: *significant at 10%; **significant at 5%; ***significant at 1%.
Sources: Computed by authors.

positive influence on the probability is exercised by whether the household operates a nonfarm income generating enterprise, the number of large animals in the previous year, and the average area irrigated. Negative influence is indicated by the share of nonfarm, nonwage income of the household, and by the rainfall shock. The age of the head and the dummy of whether the head of the household is risk averse or not are negatively significant for the decision to buy fertilizer, while education is positively significant. At the same time the dummy on whether the household is price constrained on the credit side is insignificant, while the other two credit contraint dummies (quantity rationing and risk rationing) are significant and with the proper sign. Estimations using as endogenous variables the value of all purchased inputs, as well as the value of utilized, rather than purchased fertilizer gave very similar results. The second stage in the quantity of fertilizer purchased indicates positive influence of land cultivated and agricultural capital, as one would expect. However, it indicates a negative influence of the number of big animals, which is a proxy for wealth, and this seems counterintuitive. Negative significance is exhibited by the average area irrigated, suggesting that irrigation maybe a substitute for the application of fertilizer, and by average rainfall, suggesting that worse rain implies lower fertilizer demand, as expected.

The results here appear to be compatible with the results of recent analyses of fertilizer demand in Ethiopia, such as those of Yu et al. (2011) and Zerfu and Larson (2010). From our perspective, the relevant result is that risk-related variables, such as the experience of drought in the previous year and risk aversion, as well as credit constraint variables appear to affect in the expected way (negatively) the decision to purchase as well as the demand for fertilizer. This confirms the idea that risk-related constraints are important in understanding the use of improved inputs in smallholder agriculture.

6. The *ex ante* demand for WII

As a part of our baseline data collection exercise during February–March of 2011, we conducted a Contingent Valuation (CV) study of the stated demand for index insurance. We first described the product, asking farmers whether they would generally be interested in such a product, and if not, what were the reasons. We then framed the product very specifically around the closest weather station, and instituted the yes/no question that featured prices randomized to 50, 100, 150, 200, and 250 birr.[3] The standalone insurance is framed as covering the cost of modern inputs (fertilizers and improved seeds), and is priced per-timad (one quarter of a hectare) as would befit a product covering a specific quantity of inputs. The hypothetical insurance contract would pay 1,000 birr per timad insured (the estimated cost of recommended inputs for such a land amount) in one out of every four years, so the actuarially fair price is 250 birr. For those who did want to purchase insurance, we then asked how many timad they would insure.

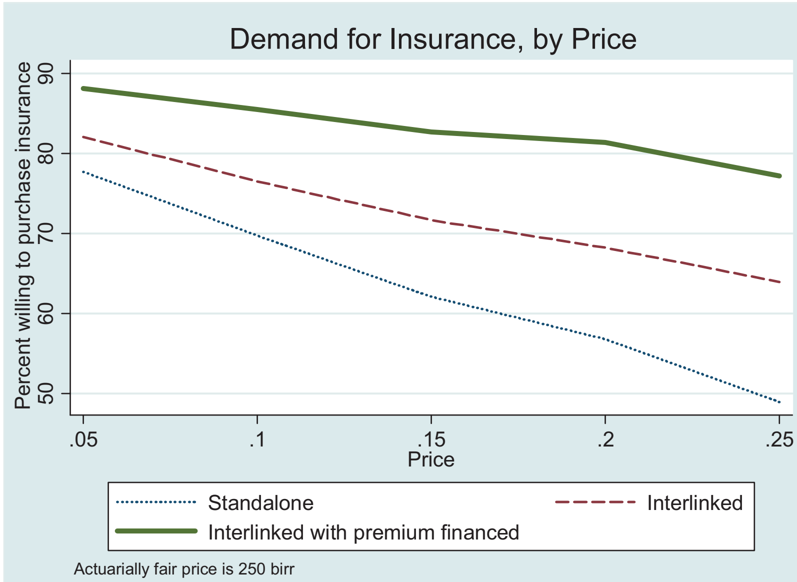
For those who did not want to purchase a standalone insurance contract (premiums paid in cash up front), we then asked the following: “Would you become interested in purchasing insurance now if you were to be able to receive the 1,000 birr worth of inputs on credit rather than having to pay for them in cash up front?” (for the basic interlinked product), and “Would you become interested in purchasing insurance if both the inputs and the insurance premium were financed by credit?” (for the full state-contingent interlinked loan). Comparison of these three questions lets us examine the stated WTP for standalone insurance, as well as the additional demand created by interlinking.

The stated WTP demand curves for each type of insurance are plotted in Fig. 1. Clearly, demand for the interlinked products is higher and less price elastic, and the demand for the interlinked product with the premium financed is even higher. However, because the interlinking questions were only asked of those who had responded that they did not want the standalone product, the rankings of these responses obtain by definition.

Concerning the reasons given by those who responded that they were not interested in purchasing the product, the primary drivers of low demand based on these purely self-reported results are the lack of money to pay for the insurance product, both generally as well as at the time inputs are needed, as well as a lack of information about the product itself. This is consistent with the results of the demand for fertilizer, illustrated in Table 6, which indicated credit constraints as major determinants of the decision to purchase fertilizer.

A probit regression on the WTP (the WTP question was asked of all households not only those that expressed interest) revealed that apart from the hypothetical offer price (which is, as expected from Fig. 1, negative and very significant) the significant variables and with the correct expected sign that appear to influence the *ex ante* WTP are (sign in parentheses) whether the head of household can read and write (+), the area of farmed land (+), the frequency of production reductions due to weather

[3] The wording of the CV exercise was as follows: “Some organizations such as Nyala Insurance are currently introducing a rainfall based insurance contract. This type of insurance covers damage to a crop during the period from its planting until harvesting resulting from drought, excess rainfall, or frost to a given crop. The spirit of the contract is that if the amount of rain as measured at a rainfall station near the Kebele is below a certain minimum; or above a certain maximum, or if there is frost you would receive a certain payout The contract will be written per Timad and you can buy as many contracts as you want. In other words, if the rainfall falls outside certain range (defined as a fraction below or above normal rainfall at a rainfall station nearest to your Kebele), or if there is a frost, you would receive a certain amount at the time of harvest. If you had bought two contracts, you would receive two times that amount. If you had bought three contracts, you would receive three times that amount, etc. and you would receive a multiple of that amount depending on the number of contracts you have bought. Obviously, such a contract would not come for free and you would be asked to pay a certain amount or premium for such a contract. The premium would have to be paid at the time of the purchase of the contract, i.e. before the planting season. We would like to know if you would be interested in such contracts and how much you would be willing to pay for such a contract. Consider the following contract. When rainfall at the weather station near the Kebele in the following year is 1/4 or more below or above normal, or if there is frost then you will be paid an amount equal to 1000 Birr per Timad. Are you willing to pay (50, 100, 150, 200, 250) Birr/Timad for such a contract?”



Source: Computed by authors.

Fig. 1. *Ex ante* demand for rainfall index insurance. Source.

shocks over the previous 10 years (+), whether the household is credit constrained (−), and whether the household had utilized a variety of coping mechanisms in previous shocks, such as relying on own savings or other family actions (−). Significant variables but with unexpected signs included a dummy on whether the head is risk averse (−), and whether the household experienced a drought shock in the previous year (−).[4]

From the results of the CV probit regression on the WTP we were also able to calculate the maximum amount of money each farming household (among those who said they would be interested in a WII product and also answered the subsequent CV question) would be willing to pay for the insurance. Albeit an estimate of the WTP can be made also for those who answered they were not interested, it would be inappropriate to compute this, as most of the estimates would be small or negative, and also without any meaning given the answer of "NO" to the question about general interest. Table 7 summarizes the estimates for the households with an expressed positive demand. The interesting observation is that the estimated average value of the WTP (277 birr) is not statistically different from the actuarially fair value of the hypothetical contract (250 birr). The same holds for the median value of the WTP. Of course if we weigh the average WTP by the share of those who indicated that they were interested, the full sample average WTP would be much lower, namely equal to $(1{,}487/2{,}399) \times 276.7 = 165.9$ birr, which is much lower than the actuarial value. This, nevertheless, suggests, *ex ante*, that the provision of WII could be met with adequate commercial demand from a significant proportion of the intended beneficiaries.

Table 7
Estimates of the *ex ante* willingness to pay (WTP) for weather index insurance (WII; values for: ¼ below or above normal rainfall or frost)

	Mean	Median	St. dev	No. of households with positive WTP*	No. of households with negative WTP
WTP (birr)	276.7	284.2	76.5	1,487	5

*The estimate of the WTP was done only for the households who indicated that they were interested in WII and hence answered the hypothetical CV questions.
Source: Authors' calculations.

7. The actual demand for WII

Approximately 18 months after the baseline exercise, teams from Nyala Insurance traveled to the 34 villages that had been randomly assigned to treatment, among the 49 villages included in the final study sample.[5] Of these 34 villages, cooperative households in 17 were offered standalone insurance contracts, while in 17 they were offered interlinked credit and insurance

[4] Note that Cole et al. (2012) also find insurance demand to be negatively correlated with risk aversion; Clarke (2011) provides a theoretical environment that motivates this regularity as a result of basis risk. The negative result on the shock in the previous year would be explained if households expect weather shocks to be negatively serially autocorrelated.

[5] Of the 120 kebeles originally selected for the pilot, the study had to be first confined to 84, which, after the baseline survey, turned out to be mostly affected by negative rainfall shocks, while the others were mostly affected by frost and floods, events for which no adequate index could be designed on the basis of available information. These kebeles were covered by 17 rainfall stations. Subsequently, the number of study kebeles had to be further restricted to 49, as the available historical record of rainfall for 10 of the 17 stations was not complete enough to allow the construction of rainfall indexes that would be acceptable by NISCO's partner reinsurance company. Of these, 34 were treatment kebeles and 15 were controls for the RCT pilot.

contracts as well as standalone insurance contracts. In the end, Nyala teams were successful in achieving sales only in 23 of these 34 cooperatives, with 12 of the 23 being in standalone villages and the remaining 9 being in interlinked ones. Problems with implementation on the supply side existed. In particular the information conveyed to the farmers was not direct, but through Ministry of Agriculture officials, "model farmers," and local extension agents. It is not clear whether the information about the nature of the insurance and interlinked credit and insurance contracts was transmitted clearly to all farmers. These supply-side problems were particularly severe in the interlinked arm, where the contract required the local CUs to guarantee the nonweather-related part of the loan, a risk which the CUs refused to accept. As a consequence the interlinked product was initially promoted as permitting access to credit, but in the end this credit failed to materialize. Consequently all contracts were ultimately standalone insurance contracts, in both standalone and interlinked kebeles.

The 20 randomly selected households in the 34 treatment villages were also included in an additional, individual-level experiment where insurance purchase vouchers ranging from 0 to 500 birr were randomly allocated to study subjects. These vouchers were distributed before the time of the marketing campaign, and could be subsequently redeemed if they bought weather insurance. This was done to increase the variability of prices faced by potential insurance buyers.[6]

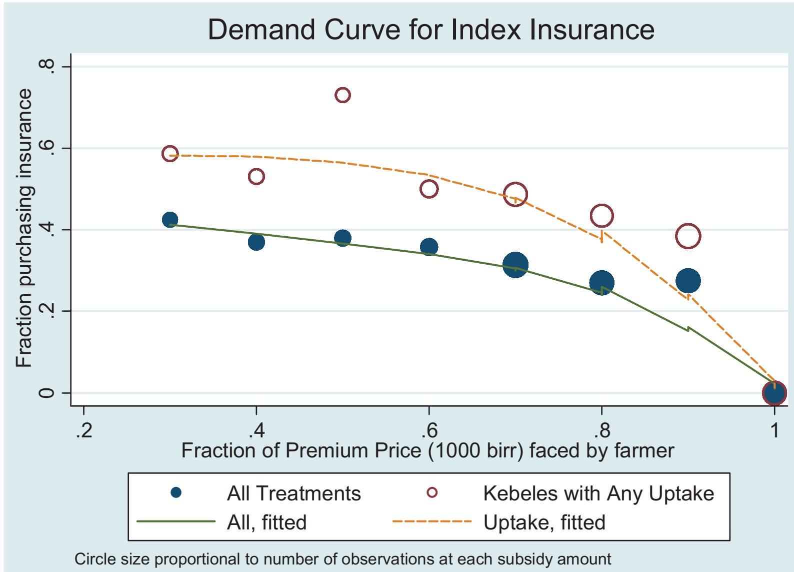
Because the purpose of this analysis is to understand the demand-side determinants of WII, we take the simple but consequential step of removing from the analysis all cooperatives in which not a single sale took place. The logic behind this step is that we cannot be sure in these cooperatives whether the constraints to adoption were on the supply or the demand side of the market, and we may confuse observational correlates of behavior at the coop level with the supply chain-driven explanations for why contracts could not be offered. Cooperatives in which at least one member purchased insurance may have had uneven promotion of the product across their membership, but we can at least be assured that there was not a hard supply-side constraint to adoption. This restricted sample thus consists of 460 observations; 20 individuals per village in the 23 villages in which at least one member purchased insurance. This restricted sample in which sales occurred proves to be broadly representative of the entire drought-prone sample of villages as well as the final study sample close to reinsured rainfall stations (results available from the authors upon request).

The 2012 sales window resulted in 202 insurance policies sold, of which 183 were sold to individuals who were in the study (the product was offered to *all* members of treatment cooperatives while we tracked only a sample of 20 households per treated village). The take-up rate in the entire final study group that we intended to treat is 25%. Within the kebeles that had any sales, the take-up rate in the study group rises to 37%. Since this latter sample is the obvious one within which to measure the demand-side determinants of take-up, we begin this analysis with a healthy take-up rate. Before being too optimistic about the overall take-up in the pilot, however, some caution is in order. First, the take-up rate in the small studied sample that received no voucher is zero. Critically for the financial success of the program, the take-up rate among the roughly 4,000 cooperative farmers who were offered the insurance but did *not* participate in the study (namely were not sampled in the baseline or given voucher) was roughly half of 1%. So, the field operations in the first year produced a very useful study sample (clean randomization, relatively high treatment rate, high uptake among study households, and very powerful effects of the voucher, which can be used as an individual-level instrument for demand), but disappointing overall market demand from the perspective of the commercial firms implementing the program. This could be due to a variety of reasons such as inadequate information and preparation, lateness in marketing, etc.

The total range of subsidy amounts over the two years ranged from zero to a subsidy that covers 70% of the intended coverage for the average sized farm. What became clear when we looked at the uptake figures is that in general rather than using the voucher amount to cover a fraction of the cost of insuring all of their land, the farmers instead used the voucher to cover all of the cost of covering part of their land. Furthermore, among those who purchased WII only 42 (21% of those buying) paid any of their own cash over and above the amount of the voucher, and of those only a little over one half (57%) paid anything over 10 birr. The insurance cover provided by our study in the first year is thus largely paid for by the randomized subsidy vouchers. Nevertheless, even among those who were given vouchers the uptake rate was around 50%. In other words even it farmers were offered a "free good," many chose not to take it.

The variation generated by the randomization of the face value of the vouchers provides clear evidence of a downward-sloping demand curve. The most striking feature, however, is the distinction between demand under any subsidy amount and demand with no subsidy. Figure 2 illustrates the result (values further to the right denote smaller subsidies). If we were to linearize the slope of the demand curve over those study subjects who received some voucher subsidy and extrapolate this linear demand to those who received no subsidy we would predict a 0-subsidy demand of over 30%. In reality, those offered a zero subsidy within the study sample had exactly zero uptake, indicating that there is an enormous effect of the vouchers (independent of subsidy amount) on realized demand. It indicates vanishingly small demand for unsubsidized index insurance even in one of the most drought-vulnerable farming populations in the world. This focuses our attention on the slow process of building a WII market, and the critical role played by marketing and outreach activities by the insurance company when complex new products are introduced.

[6] Some households also received small vouchers during the baseline period of 2010. These were added to the vouchers offered during the 2012 campaign.



Source: Computed by authors.

Fig. 2. Demand for weather index insurance as a function of the fraction of premium price paid by farmer.

We next explore whether the actual uptake of WII is related to the *ex ante* WTP from the CV analysis.[7] If we can illustrate that the stated WTP is a good proxy for actual demand, this would greatly ease future research geared around identifying promising locations and markets for index insurance products. Unfortunately, in our study, stated and actual demand are very poorly correlated, and in fact in several reasonable specifications they display a *significant* and *negative* correlation with each other. Among those who self-reported as being willing to buy the actuarially fair insurance product in the CV stated demand exercise actual uptake was 37.2%, while among those who said they would not buy that product, uptake was 44.3%. Table 8 illustrates this effect via simple probit regressions. Column 1 provides the simple binary/binary correlation correcting for clustering at the village level, and shows a negative albeit not significant relationship. The other two columns, clearly indicate that the major determinant of *ex post* uptake is the voucher offer and amount, while the *ex ante* WTP is insignificant or negatively correlated. Different specifications of the regression produced similar results.

Of the 183 actual purchases in our survey data, 92 had indicated they would be willing to purchase *ex ante*, and 91 indicated they would not. Given that most insurance purchases involved using the voucher only, it is perhaps particularly surprising that there were 114 individuals who indicated that they would purchase the *ex ante* insurance and then did not buy actual insurance despite having a nonzero voucher and being located in villages where sales did take place. When we examine how those with vouchers who said they would purchase and then didn't buy

Table 8
Regression of actual uptake on the *ex ante* desirability of weather index insurance (WII) in baseline

Marginal effects probit with standard errors clustered at the kebele level

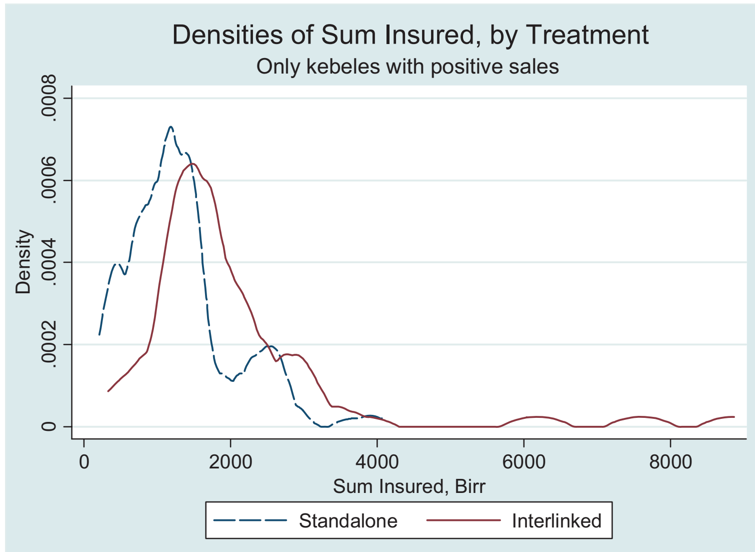
	Purchased insurance	Purchased insurance	Purchased insurance, kebele-fixed effects
Ex ante WTP = yes	−0.0653	−0.0777*	−0.0176
	(0.039)	(0.040)	(0.040)
Received voucher		0.344***	0.375***
		(0.068)	(0.064)
Voucher amount		0.421**	0.392**
		(0.153)	(0.156)
Ex ante WTP study randomized price		−0.278	−0.193
		(0.228)	(0.237)
Number of households	460	460	460

Standard errors in parentheses below point estimates: *significant at 10%; **significant at 5%; ***significant at 1%.
Source: Authors' computations.

differ from those in the same state who did ultimately buy, we see again that the use of chemical fertilizer is the key driver of actual sales, with those who ultimately purchased being less likely to use organic fertilizer and more likely to use chemical fertilizer (results available from authors upon request).

It is worth pointing out a few dimensions in which our stated demand study is not ideal for comparison with actual demand. First, the CV WTP exercise was conducted during the baseline survey, meaning that it preceded the sales window by roughly 16 months. If demand for insurance is time-varying, this will tend to decrease the correlation between any two measures taken such a long time apart. Second, because the exact contract terms for the final product were not known when we did

[7] Note that the randomized actual voucher amount and the randomized price used in the *ex ante* WTP exercise are properly balanced and orthogonal to each other.



Source: Computed by authors.

Fig. 3. Densities of sums insured in the two treatment arms, standalone and interlinked.

the WTP exercise, the hypothetical product does not coincide exactly with the one that was eventually sold. The CV question refers to an insurance against excess rainfall, deficit rainfall, or frost, while the actual product is only for deficit rainfall. Thus the correspondence between the hypothetical and actual product is not perfect, but the presence of a negative correlation between stated and actual demand is nonetheless discouraging for the idea that hypothetical demand surveys can reveal useful information about uptake in this context.

Albeit no interlinked contracts were sold, the information conveyed to farmers in the two arms was different, and this may have induced differences in the uptake rates. Specifically, farmers in the interlinked arm believed that credit would be made available to them up to the amount of the sum insured, although in the end the intermediaries were unwilling to take on the risk of providing this credit during the first year of the pilot. The unadjusted take-up rates of insurance contracts are 44.5% in the standalone arm and 35% in the interlinked arm. If we adjust for the voucher amounts and cluster the standard errors at the village level, this difference is not significant. When we examine the sum insured, and as Fig. 3 shows, the distributions of the quantity of cover purchased by those who did take up insurance in the two arms are different, with the distribution strongly shifted to the right for the interlinked arm. Among those purchasing insurance, the average sum insured in the standalone arm was only 1,295 birr, while in the interlinked arm it was 2,018. This difference is significant at just below the 90% level. Overall then, the interlinked arm saw somewhat lower take-up overall, but for those who did choose the product they demanded a large sum insured. This pattern is consistent with interlinked farmers purchasing more insurance coverage so as to gain access to enough credit to cover their entire input purchase for the year.

Table 9 pursues the connection between constraints to input use and the demand for insurance by regressing both the *ex ante* and the realized demand for insurance on the farm-level marginal products of inputs (land, labor, and capital) derived from the analysis in Section 4. If risk is a driving constraint to the use of inputs, then we would expect to find those with high marginal products of land and particularly of capital to desire insurance. This relationship would suggest a "transformative" role for WII in relaxing constraints for those who currently underuse inputs. On the other hand, it may be the case that those who do not use inputs have little demand for financial protection for input risk, and hence those with the highest demand are those with the highest use of inputs and thus the lowest marginal products. This would suggest a more "palliative" role for insurance; protecting those most exposed but not necessarily enabling an expansion of input use.

Column 1 in Table 9 shows the relationship between *ex ante* demand and these marginal products, finding evidence of the "transformative" pattern with respect to the marginal product of inputs. Those with the highest marginal products of labor and inputs have the highest stated WTP for insurance, suggesting the presence of risk as a major constraint in input use. Those with low marginal product of land (suggesting that they use more land than what would be efficient) seem to demand more WII. Unfortunately, when we turn to actual insurance demand in column 2 we find no evidence of such relationships. Column 3 focuses on uptake only in the interlinked arm (where the connection between insurance purchases and input decisions is more concrete) and finds evidence of the "palliative" relationship; those with low marginal products (and hence closer to efficient use of inputs) are most likely to purchase insurance. Columns 4 and 5 examine the sum insured and the amount of own cash put into the contract (above the value of

Table 9
Marginal products as determinants of weather index insurance (WII) demand

	Whole study sample in kebeles with any sales:		Interlinked villages only:	Among those purchasing insurance:	
	Stated willingness to pay	Purchased insurance	Purchased insurance in interlinked arm	Sum insured	Amount of own cash used in purchase
CV price in WTP survey	−1.542***				
	(0.322)				
Received voucher		0.402***	0.644***	1,981***	−6.71
		(0.136)	(0.195)	(492.500)	(9.007)
Voucher amount		0.339***	0.221***		
		(0.051)	(0.071)		
Marginal product of labor	0.000713***	−0.0000564	0.000258	2.137	0.0132
	(0.000)	(0.000)	(0.000)	(2.060)	(0.029)
Marginal product of land	−8.19e−06***	−0.00000261	−0.00000851	−0.0434	−0.0000281
	(0.000)	(0.000)	(0.000)	(0.029)	(0.000)
Marginal product of inputs	0.00809**	−0.00547	−0.0221***	−30.91***	−1.050***
	(0.003)	(0.004)	(0.005)	(10.540)	(0.383)
No. of households	440	440	194	175	175

Robust linear probability model, standard errors reported in parentheses
Standard errors in parentheses below point estimates: *significant at 10%; **significant at 5%; ***significant at 1%.
Source: Authors' computations.

the voucher) among individuals who purchased insurance. Again, the marginal product of inputs is strongly negatively significant, suggesting that more insurance is purchased and more cash is put in by those who were closest to efficient use of cash inputs to begin with. Overall then, the pattern of realized demand is strongly suggestive of the "palliative" pattern, whereby insurance would be protecting those who were anyways heavily exposed to input risk because of strong demand in the absence of insurance.

Tables 10 and 11 exhibit the results of regressions aimed at exploring a variety of determinants of the actual uptake of the WII contract. Table 10 explores the demographic and economic determinants of demand, showing the pooled demand for both products together as well as the segregated regressions showing demand for each type relative to the control separately. Table 11 shows regressions demonstrating the behavioral factors and basis risk determinants of demand. It can be seen that apart from the voucher dummy (which simply indicates whether the household received a voucher) and the voucher amount, very few other variables explain the uptake of WII. Among economic variables the per capita income is negatively correlated with uptake, indicating perhaps that wealthier households do not need WII. On the other hand the use of chemical fertilizer affects positively the uptake, and this is consistent with the *a priori* hypothesis that use of fertilizer and hence need for cash outlays could be affected by WII. It is also consistent with the analysis in Table 9 suggesting that those with low marginal products of cash inputs display the highest demand for WII. Further, since the insurance is explicitly intended to cover the cost of inputs, it is most obviously relevant for those who are already using chemical fertilizer. Behavioral variables and covariates measuring the extent of basis risk appear to have quite a weak effect on realized demand.

8. Conclusions

The results presented in this article highlight the challenges of designing and implementing pilot RCT experiments involving commercial WII products. Introduction of such products involves the collaboration of many different institutions, which must be coordinated appropriately to make the introduction of WII a success. In the EPIICA case implementation of the pilot experiment was imperfect. Starting with the design, while the hypothesis was that the main risk faced by households in the nonrandomly selected kebeles was rainfall deficit, it turned out that in only two thirds of the villages where the study was implemented, the main risk faced was rainfall deficit. Second, it turned out that the availability of rainfall data is something that cannot be taken for granted. Data gaps can negatively affect the possibility for estimating appropriate actuarial tables and hence the proper pricing of WII products. Nevertheless, there was successful implementation in the second year of the project, and results from this can be assessed.

The first results of this article are that (as hypothesized) there appear to be significant profitable opportunities for increased fertilizer use in the fertile highlands of Ethiopia, but farmers are constrained on both the cash availability side, as well as the credit side. The marginal products of fertilizer use are significantly above market values, while the marginal products of labor are significantly below market values. These results, which have also been found in other African countries, underscore the importance of means to increase agricultural productivity via expanded modern input use. Among the factors that condition fertilizer use, it was seen that risk factors as well as credit constrain factors are significant, thus supporting the underlying hypotheses of the effort to promote WII as a means to expand agricultural credit.

Table 10
Demographic determinants of WII uptake (marginal effects probit with standard errors clustered at the kebele level; dependent variable is a binary variable, which is equal to 1 if the household bought WII and 0 otherwise)

		Purchased standalone insurance	Purchased interlinked insurance
Voucher amount	0.397**	0.286	0.506**
	(0.152)	(0.239)	(0.209)
Any voucher	0.380***	0.437***	0.273***
	(0.070)	(0.107)	(0.079)
Insurance promotion at baseline	0.000526	0.0271	−0.0429
	(0.047)	(0.075)	(0.055)
Age of household head	0.00118	0.000669	0.00274
	(0.001)	(0.002)	(0.003)
Household head literate	0.026	0.0114	0.0255
	(0.048)	(0.075)	(0.060)
Household size (adult equivalents)	0.0122	0.026	−0.00716
	(0.016)	(0.020)	(0.017)
Income per household member	−2.08e−05*	−0.0000254	−0.0000167
	(0.000)	(0.000)	(0.000)
Number of large animals owned	−0.0147	−0.00974	−0.0294
	(0.011)	(0.012)	(0.020)
Total area of land cultivated (hectares)	−0.0411	−0.084	0.0403
	(0.049)	(0.061)	(0.048)
Area of land irrigated (hectares)	−0.0161	0.154	−0.0634
	(0.138)	(0.135)	(0.094)
Chemical fertilizer used?	0.177**	0.118	0.295***
	(0.065)	(0.093)	(0.062)
Household is credit constrained	0.00595	0.112	−0.067
	(0.065)	(0.073)	(0.091)
Household experienced drought in past 12 months	−0.0781	−0.0409	−0.0429
	(0.093)	(0.127)	(0.098)
# Of last 10 years in which shock experienced	−0.00659	−0.000965	−0.0168
	(0.016)	(0.024)	(0.018)
Number of households	442	250	192
R-squared	0.211	0.229	0.288

Standard errors in parentheses below point estimates: *significant at 10%; **significant at 5%; ***significant at 1%.
Source: Authors' computations.

Table 11
Behavioral and basis risk determinants of WII uptake (marginal effects probit with standard errors clustered at the kebele level; dependent variable is a binary variable, which is equal to 1 if the household bought WII and 0 otherwise)

	Behavioral determinants	Basis risk
Voucher amount	0.371**	0.399**
	(0.170)	(0.156)
Any voucher	0.360***	0.356***
	(0.072)	(0.073)
Impatient	−0.119	
	(0.076)	
Hyperbolic	−0.0194	
	(0.072)	
Risk averse	−0.00285	
	(0.064)	
Numerate	−0.00325	
	(0.051)	
Trusting	0.0411	
	(0.058)	
Trusts financial institutions	−0.0676*	
	(0.033)	
Trusts the cooperative	0.036	
	(0.033)	
Trusts district government	0.0223	
	(0.050)	
Distance to nearest rainfall station (km)		0.00232
		(0.009)
Elevation difference to nearest station (m)		0.000264
		(0.000)
Distance to kebele center (km)		−0.00394
		(0.027)
Elevation difference to kebele center (m)		−0.000653*
		(0.000)
Average distance from household to plots (minutes)		0.00101
		(0.001)
Household reports different rainfall from kebele		0.0179
		(0.032)
Number of households	418	450
R-squared	0.185	0.178

Standard errors in parentheses below point estimates: *significant at 10%; **significant at 5%; ***significant at 1%.
Source: Authors' computations.

Is it realistic to expect smallholder farmers to utilize fertilizer at commercially efficient levels? Barrett (2008) discusses the extensive barriers to market participation in eastern and southern Africa that prevent many smallholder producers from selling in the market at all. However, our context appears to provide some cause for optimism. First, we have selected a sample of villages with good agricultural prospects and access to markets. Second, because we focus on cooperativized farmers, all of our target farmers are marketing some part of their surplus and have access to the types of intermediary institutions that are critical to commercialization in this context. The particular institutional setting on Ethiopia, with the government monopolizing the procurement of fertilizer and guaranteeing credit to agriculture seems to create additional risks and constraints to farmers, especially when the rainfall is inadequate and farmers have to repay the loans at a time when they are faced with low production and incomes.

In such a context, one would anticipate that the demand for commercial WII would be substantial. It turned out that *ex ante*, demand was indeed high, and in fact on average farmers were found to be willing to pay the actuarially fair cost for WII. On the other hand, when offered the actual product, demand was lower, and significantly influenced by the availability and amounts of subsidy vouchers. Given that most states in Ethiopia are now moving away from the subsidization of credit for inputs, finding innovative ways to pull private credit into smallholder agriculture and to protect farmers from weather-related default risk appears to be particularly timely.

These results and the lack of correlation between the *ex ante* and *ex post* demand for WII could be due to a host of implementation issues. As was mentioned the information transmission mechanism to farmers was inadequate for a new and rather complicated financial product, such as WII. Second, the various delays in implementation implied that when the product was actually marketed, many farmers might have already bought the fertilizer they intended to use on cash, and hence they might have already incurred the investment, hence not needing insurance for an amount already spent, and fertilizer decisions already made. Third, the timing of the marketing and insurance sales did not pay attention to the availability of cash. As Duflo et al. (2010) have emphasized, time inconsistencies, along with cash constraints at critical times may affect considerably the demand for fertilizer, and possibly also the demand for WII.

The overall conclusion from the insurance purchases in our study is that some factor is prohibitive to purchases in the greater population, and that promotion and subsidy will be necessary for a more widespread adoption of index insurance at the farmer level in Amhara.

The insurance uptake observed among study subjects turned out to be healthy, but was negligible among those who were not offered subsidies. This helps to focus attention on the slow process of building a WII market, and the critical role played by marketing and outreach activities by the insurance company when this product is newly introduced.

One of the rather surprising conclusions of the analysis was that the *ex ante* WTP for WII does not seem to be correlated with the *ex post* actual demand (in fact, they are negatively correlated!). This may have been the case in our experiment because of the institutional implementation issues, or because the time delay between the period when the *ex ante* WTP was assessed and the actual sales was considerable, and circumstances may have changed in between. Regardless, our results provide no evidence that stated WTP studies provide a useful picture of actual demand for index insurance products.

Our examination of the determinants of *ex post* demand for WII revealed that subsidy vouchers, even at very small cash amounts, are a very effective way of driving uptake for WII. In addition, high fertilizer use (indicating a lower marginal product of cash inputs) is a strong determinant of insurance uptake, the sum insured, and the amount of own cash that farmers put into buying insurance. This suggests that the product is likely to provide protection primarily to those who were already using inputs at high levels, rather than enabling a "transformative" increase in input use among those who had not previously used them. Variables related to behavioral attributes or to basis risk appear to have little predictive power on insurance purchase decisions.

The overall takeaway message from the empirical analysis is that designing risk management products such as WII in developing country context is a challenging proposition. The empirical results reported here refer to only the first sales year of a multiyear pilot. They have helped clarify many implementation and institutional issues, and have helped understand some of the problems and difficulties in implementing commercially viable WII products, but at the same time have raised several interesting questions. Subsequent envisaged rounds of this pilot will hopefully produce much cleaner and robust conclusions.

Acknowledgments

The authors acknowledge the excellent collaboration of Degnet Abebaw and Assefa Admassie of the Ethiopian Economic Association, who organized and supervised the collection of the survey data utilized in this article. They also thank Shukri Ahmed, Rene Gommes, and Alixa Sharkey, as well as several staff of Nyala Insurance Company (NISCO) in Ethiopia, especially Eyob Maherete, Demelash Birarra, and Biniam Taddese, for helpful suggestions, comments, and assistance throughout the research described herein. They also thank three anonymous referees for very careful and thorough reviews of the first draft. The work described in this article was financed by the Index Insurance Innovation Initiative (I4), under a grant from USAID.

Appendix: Estimation of the production function and marginal products of inputs

Our estimation of the production function uses the following general form:

$$\text{In}Q = \alpha + \Sigma\beta_i \log X_i + \Sigma\gamma_j Z_j + u, \tag{A.1}$$

where Q is a measure of the value of production of a farm, X_i are factors of production such as land, labor, intermediate inputs, and capital, β_i are the estimated coefficients of each factor (the elasticities, if the log specification is chosen), Z_j are TFP determinants such as household characteristics, and u is an i.i.d. error term.

The dependent variable is equal to the gross value of total farm crop output. In our setting, explanatory variables such as inputs of labor, as well as intermediate inputs, may be considered as endogenous variables and jointly determined with Q and thus dependent on the stochastic disturbance. Land in Ethiopia is allocated by the government and the rental market is almost nonexistent. In our survey there were no observations of land rentals. Hence we consider land cultivated as pre-determined. Similarly, the stock of agricultural capital is pre-determined as it has been procured in periods before the current one. To avoid biases in the estimates we used instrumental variables to estimate the two endogenous variables.

For the production function analysis, we use several sets of explanatory variables. First we utilize the standard factors of production, namely land, labor, capital, and intermediate inputs (purchased and own produced). We also use a dummy variable, which is equal to 1 if the household hires labor for crop production. This variable is supposed to capture whether the household is facing supervision constraints in hired labor. If this is the case the sign of this variable should be negative. Second we utilize household and farm characteristics such as age and education of the head, number of parcels, share of land irrigated, and land quality and location characteristics, such as average rainfall, average slope, and average altitude. We utilize also several household characteristics, such as whether the head is risk prone or averse, whether he/she is an officer in the kebele council, and whether the household operates a nonfarm enterprise. Finally we utilize dummies for drought and flood shocks in the relevant year.

To control for endogeneity of intermediate inputs, and labor, we have used, as a set of instruments the following: credit constraints (variables related to credit access, such as credit constraints have been hypothesized for a long time to affect the use of inputs and hence production [Eswaran and Kotwal, 1986; Feder, 1995]; the basic assumption used in all studies is that assets, including land, affect positively the availability of credit and through this the availability of inputs and hired labor, and hence they should affect positively land and agricultural productivity). We also utilize a dummy for whether any member of the household has a bank account. We use the number of bullocks or oxen 12 months ago as an instrument since this should correlate well with wealth and access to credit and finance. Additional instruments include the log of hired labor prices, and the logs of prices of the two types of inorganic fertilizer (Urea and DAP). All these can be considered as exogenous to the household. Finally we use the membership in the local cooperative since this could influence the access to credit for inputs.

Table A1 indicates the estimation of the agricultural crop production function for our sample in Amhara, under OLS with kebele-fixed effects, and under IV also with Kebele-fixed effects. All primary factors of production, are significant. The dummy for whether the household hires labor is not significant, indicating that supervision constraints do not exist. Of the several other variables introduced, the significant ones include the age of the household head (−), the number of parcels in the cultivated land (+), the share or land that is irrigated (+), the dummy or whether the household head is risk prone[8] (+), and the dependency ratio (+). Table A2 indicates the first stage regressions on the endogenous variables. It can be seen that several of the instruments are significant and with the expected signs, and that the first stage regressions explain a large amount of the endogenous variables variance. The F-test for the hypothesis that the sum of the coefficients on the land, inputs, labor, and capital variables is equal to 1 is rejected, and the sum of these coefficients is larger than 1, suggesting increasing economies of scale. Furthermore, the Wu–Hausman and the Durbin–Wu–Hausman tests reject OLS compared to the IV specification.

For each farmer (we omit an index of the farmer to simplify notation) the marginal product of factor X_i can be calculated as follows:

$$MPX_k = \frac{\partial Q}{\partial X_k} = \left(\frac{\partial \ln(Q)}{\partial \ln(X_k)}\right)\frac{Q}{X_k} = \beta_k \frac{Q}{X_k}, \qquad \text{(A.2)}$$

where β_k is the estimated Cobb–Douglas regression coefficient for factor X_k.

[8] As defined in the questionnaire, higher values of this variable imply that the respondent is less prone to assuming risks.

Table A1
Estimation of the crop production function

Dependent variable: log of gross value of crop production[a]	OLS estimation with kebele-fixed effects	IV estimation with kebele-fixed effects
Log of value of crop inputs used[b]	0.193***	0.477***
	(0.026)	(0.139)
Log of total labour (in months) used[b]	0.132***	0.827***
	(0.041)	(0.284)
Log of hectares cultivated	0.302***	0.133**
	(0.052)	(0.057)
Log of value of agricultural capital	0.147***	0.070**
	(0.021)	(0.033)
Dummy for hired labor	0.087***	0.049
	(0.035)	(0.054)
Log age of household head	0.029	−0.170**
	(0.065)	(0.088)
Household head's education in years	0.001	0.006
	(0.008)	(0.008)
No. of parcels cultivated	0.100***	0.056***
	(0.010)	(0.0125)
Share of land irrigated	0.404***	0.252*
	(0.135)	(0.150)
Average rainfall index	−0.035	−0.034
	(0.025)	(0.035)
Average slope index	0.044	0.070
	(0.037)	(0.046)
Average altitude index	0.026	0.044
	(0.027)	(0.035)
Risk prone dummy	0.003	0.089*
	(0.037)	(0.051)
Risk averse dummy	−0.251**	−0.133
	(0.107)	(0.113)
MFI membership dummy	−0.018	−0.002
	(0.035)	(0.041)
Female household head dummy	−0.058	0.122
	(0.057)	(0.091)
"Officer" in the household dummy	0.070	−0.024
	(0.054)	(0.056)
Dependency ratio	0.119	0.346**
	(0.087)	(0.151)
Average farm distance from household	0.000	0.000
	(0.001)	(0.001)
Dummy = 1 if anyone in the household has an income generating micro enterprise	−0.032	−0.009
	(0.053)	(0.061)
Dummy = 1 for drought (shock)	0.082	0.060
	(0.064)	(0.072)
Dummy = 1 for flooding (shock)	−0.068	−0.069
	(0.052)	(0.068)
Constant	4.437***	0.565
	(0.428)	(1.232)
Observations	2314	2232
R-squared	0.6535	0.5060
Test for returns to scale		
Test H0 = land+ inputs+ total labor + agricultural capital = 1		
F-value	16.02	6.16
P-value	0.0001	0.0131
Test of endogeneity H0 = variables are exogenous		
F-value		18.4856
P-value		0.0000

Note: Instruments used: Credit constrained dummy; Bank account dummy No. of draft bullocks or oxen 12 months ago; Log hired labor prices; Log price of inorganic fertilizer—UREA; Log price of inorganic fertilizer—DAP; Head or anyone else in the household member of a cooperative.
Standard errors shown in parentheses below point estimates. *significant at 10%; **significant at 5%; ***significant at 1%.
[a]Standard errors clustered at the kebele level.
[b]Variable instrumented for IV estimation.
Source: Computed by authors.

Table A2
Results of the first stage regressions of the IV estimation of crop production with kebele-fixed effects

	Value of crop inputs used[a]	Total labor used[a]
Log of hectares cultivated	0.283***	0.090***
	(0.064)	(0.025)
Log of value of agricultural capital	0.044*	0.061***
	(0.026)	(0.015)
Dummy for hired labor	0.196***	−0.042
	(0.058)	(0.034)
Log age of household head	−0.028	0.219***
	(0.066)	(0.040)
Household''s head education in years	0.006	−0.006
	(0.008)	(0.004)
No. of parcels cultivated	0.080***	0.018***
	(0.013)	(0.007)
Share of land irrigated	0.561***	0.024
	(0.162)	(0.060)
Average rainfall index	0.007	−0.007
	(0.034)	(0.025)
Average slope index	−0.051	−0.023
	(0.042)	(0.026)
Average altitude index	−0.102***	0.017
	(0.037)	(0.018)
Risk prone dummy	−0.047	−0.106***
	(0.050)	(0.030)
Risk averse dummy	−0.111	−0.127*
	(0.114)	(0.068)
MFI membership dummy	−0.063	−0.017
	(0.047)	(0.027)
Female household head dummy	−0.044	−0.173***
	(0.073)	(0.041)
"Officer" in the household dummy	0.105*	0.061***
	(0.058)	(0.024)
Dependency ratio	0.001	−0.329***
	(0.098)	(0.064)
Average farm distance from household	0.000	0.000
	(0.001)	(0.001)
Dummy = 1 if anyone in the household has an income generating micro enterprise	0.069	−0.070**
	0.069	−0.070**
	(0.053)	(0.032)
Dummy = 1 for drought (shock)	−0.126*	0.078**
	(0.068)	(0.039)
Dummy = 1 for flooding (shock)	0.048	−0.012
	(0.075)	(0.034)
Credit constrained dummy	−0.113**	0.016
	(0.049)	(0.025)
Bank account dummy	0.021	0.075**
	(0.070)	(0.034)
No. of draft bullocks or oxen 12 months ago	0.089***	0.070***
	(0.020)	(0.014)
Log of hired labor prices	0.097*	−0.007
	(0.055)	(0.029)
Log of price of inorganic fertilizer—UREA	−0.248**	0.017
	(0.113)	(0.017)
Log of price of inorganic fertilizer—DAP	−0.056	−0.013
	(0.046)	(0.015)
Head or anyone else in the household member of a cooperative	0.081	0.065**
	(0.064)	(0.030)
Constant	10.534***	1.720***
	(0.622)	(0.240)
Observations	2,232	2,232
R-squared	0.7246	0.2937

Standard errors shown in parentheses below point estimates.
*Significant at 10%; **significant at 5%; ***significant at 1%.
[a]Standard errors clustered at the kebele level.
Source: Computed by authors.

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