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Incomplete Markets and Fertilizer Use

Evidence from Ethiopia

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Abstract

While the economic returns to using chemical fertilizer in Africa can be large, application rates are low. This study explores whether this is due to missing and imperfect markets. Results based on a panel survey of Ethiopian farmers suggest that while fertilizer markets are not altogether missing in rural Ethiopia, high transport costs, unfavorable climate, price risk, and illiteracy present formidable hurdles to farmer participation. Moreover, the combination of factors that promote or impede effective fertilizer markets differs among locations, making it difficult to find a single production technology that is uniformly profitable—perhaps explaining the inconsistency between field studies finding large returns to fertilizer use in Ethiopia and survey-based studies finding fertilizer use to be uneconomic. The results suggest that households with greater stores of wealth, human capital and authority can overcome these hurdles. The finding offers some encouragement, but also implies a self-enforcing link between low agricultural productivity and poverty, since low-asset households are less able to overcome these problems. The study suggests that the provision of extension services can be effective and that lowering transport costs can raise the intensity of fertilizer use by lowering the cost of fertilizer and boosting the farmgate value of output.

This paper—a product of the Agriculture and Rural Development Team, Development Research Group—is part of a larger effort in the department to discover ways to improve the productivity of African farmers. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at DLarson@worldbank.org. This study was supported by the Knowledge for Change Program, under the project title, "An African Green Revolution: Finding Ways to Boost Productivity." The authors thank Derek Byerlee, Peter Hazell, Kei Kajisa, Keijiro Otsuka and participants at a Tokyo workshop in December 2009 for suggested improvements to an earlier draft.

Incomplete markets and fertilizer use: Evidence from Ethiopia

Daniel Zerfu and Donald F. Larson

Keywords: agriculture, Ethiopia, Green Revolution, fertilizer, panel data, selection model

Introduction

On average, agricultural productivity in Africa is lower than in other regions and available technologies that show great promise in field studies are not widely adopted. Consequently, the gains in rural income and the reduction in rural poverty that characterized Asia's Green Revolution have not reached Africa. Several reasons are given for the slow pace of productivity growth in African agriculture, but many researchers and policy makers view the limited take up of fertilizers as a key proximate cause. At present, most productive technologies depend on abundant soil nutrients. In Africa, soils are depleted in many places and practices aimed at boosting soil fertility, including the application of chemical and organic fertilizers, are not commonplace. Moreover, studies suggest that because of this, nutrients are continually extracted from African soils to feed current crops.[1] For these reasons, the under-utilization of fertilizers is viewed as a hurdle to the adoption of more productive and sustainable agricultural techniques.

Several arguments are advanced to explain why fertilizer use is low in Africa, including some that suggest failed markets. In turn, this has prompted calls for African governments to take a more active role in fertilizer markets and to offer targeted subsidies that promote the use of fertilizers, high-yielding seeds and other components of more productive techniques.[2]

In this paper, we investigate the role incomplete markets play in determining the use of chemical fertilizers among Ethiopian farmers with the aim of identifying policies that would encourage the adoption of profitable and sustainable agricultural practices. We use panel data to estimate a selection model and this allows us to distinguish empirically between determinants that condition the use of fertilizer and those that affect the conditional quantities of fertilizer that farmers demand. The panel data that we employ is well suited to our purpose since it contains a relatively even mix of farmers that use fertilizers and those that do not. The survey also contains information that we use to proxy the effects of incomplete credit and insurance markets, and information hurdles that are related to how well fertilizer markets work. The survey also contains information about characteristics that potentially help households cope with poorly functioning markets.

Empirical results from the panel selection model suggest that a variety of factors stand in the way of the widespread adoption of fertilizer-using production technologies in Ethiopia. Chief among these are high transport costs, illiteracy, adverse local climates, and limitation in risk and credit markets. Households that are wealthier, better educated, or have greater political authority are better able to overcome obstacles to adoption; however, this, in turn, suggests a reinforcing effect on rural poverty as less-advantaged households

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[1] Henao and Baanate (2006), reported in Morris et al. (2007), estimate that 85 percent of African farmland suffer soil nutrient loses at a rate of 30 kg per year or greater.

[2] See, for example, the Abuja Declaration (2006), issued during the 2006 Africa Fertilizer Summit.

continue to rely on less productive farming techniques that continue to deplete soils. At the same time, the results suggest that fertilizer markets are not all together missing in rural Ethiopia, and that government actions to close knowledge gaps and lower transportation costs can increase fertilizer use among farmers.

With this as background, the rest of the paper is organized as follows. The next section provides additional background information about Ethiopian agriculture and related studies of fertilizer demand. The following section develops the empirical model. The next sections present the descriptive statistics followed by the empirical results. The last section concludes.

Background

Agriculture is the mainstay of the Ethiopian economy with its hefty contribution of about half of the GDP. Yet its growth rate over the past four decades had been quite low. Per capita agricultural output in 2003 is not so much different from its level in 1961. This is coupled with the dominance of smallholder farmers with land holding size of 0.96 hectare per household, and yield of 1,167 kg to 2,122 kg per hectare for the main cereal crops (CSA, 2008). As a consequence, few farming households produce significant surpluses to market and many are unable to consistently feed themselves.[3] Yet results from research stations and pilot programs suggest that the economic returns to fertilizer, when combined with improved seeds and better farming techniques can be high (Bekele and Höfner, 1993; Howard et al. 2003). This has prompted the Government of Ethiopia to emphasize agriculture in its economic growth strategy, Agriculture Development Led Industrialization (ADLI). And in particular, the government and donors have supported a number of productivity-enhancing efforts, such as the provision of extension services, the introduction of high yield variety seeds and the timely provision of chemical fertilizers.[4]

Between 1991 and 1995, fertilizer use and intensity in Ethiopia rose dramatically from 110,000 metric tonnes (21 kg/ha) to 300,000 (35 kg/ha) in 1999, levels that compare favorably with many countries in Africa (World Bank, 2006). Nevertheless, in subsequent years, fertilizer consumption and intensification fluctuated considerably and intensification has only recently resumed a steady upward trend. Consequently, like many countries in Africa, the penetration of productivity enhancing inputs such as chemical fertilizer, improved seeds, and pesticides is very low. As a proportion of the total crop area at the national level, around 45% is treated with chemical fertilizer (with the average application of 81 kg per hectare) and only 15.2 % is treated with by pesticides. Only 3.5% of the land is planted with improved seeds and extension agents only reach 11% of total cropland (CSA, 2008).

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[3] Demeke et al (1998) noted that 790 kg of grain is needed to meet the minimum calorie requirement assuming 156 kg / person/year grain requirement for a household of five.

[4] See Byerlee et al. (2007) for a discussion of government policy aimed at promoting fertilizer use in Ethiopia.

Several arguments are offered in the economics literature about why fertilizer use is low in Ethiopia and among African farmers generally.[5] Not all of the arguments imply failed markets, though several do. In particular, some economists argue that because natural and man-made transportation systems are poorly developed in Africa, high transport costs work to raise the price of inputs and lower the farm-gate price of goods destined for distant urban centers. This discourages the use of chemical fertilizers in particular, which, in Africa, are mostly imported. Consequently, techniques that prove profitable in Asia, where populations and transport systems are denser, are uneconomic in Africa.[6] Other policies can exacerbate this problem. For example, in a comparative study, Jayne et al. (2003) gives examples of policy-driven charges, including port charges and fuel taxes, that add to already high input costs.

That a supply of fertilizer is unavailable locally when all farmers find fertilizer use uneconomical would not be a market failure as such, since it does not imply that resources are misallocated. However, farms and farmers are heterogeneous and it may be the case some farmers who would purchase fertilizer find supplies difficult to obtain when aggregate local demand is not sufficient to attract traders to remote locations. This is especially true when demand is spatially dispersed and highly unpredictable due to variable output prices and weather conditions. Consequently, the locations were fertilizers can be purchased may be distant, leading to higher transaction costs.[7]

A much discussed obstacle to fertilizer use and the take-up of new technologies has to do with risk and missing insurance markets. High-yielding farming methods often require greater up-front investments in inputs and labor that are at risk should crops fail. Consequently, farmers may rationally choose low-productivity approaches that lower investment risks and allow households to diversify limited labor resources.[8] For similar reasons, farmers who are willing to take on riskier technologies may be unable to finance up-front input purchases since the same risks faced by farmers may also make formal and informal lenders hesitant to provide credit to farmers and to input suppliers.[9] Potentially, production risks to farmers and lenders could be addressed by insurance or other contractual arrangements. However formal insurance markets are hampered by asymmetric information problems and often poorly supported by weak institutions. Informal approaches for sharing risk can work well when risks are idiosyncratic, but fail in the face of systemic risks like drought.[10]

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[5] For a related discussion in the context of Ethiopia, see Croppenstedt and Demeke (2003).

[6] See the general discussion in Sachs et al. (2004). Morris et al. (2007) provide estimates based on case studies from Africa.

[7] Gregory and Bumb (2006) provide examples. Xu et al. (2009) discuss how heterogeneity in local conditions affects the profitability of fertilizer use.

[8] See Dercon (1996), and Dercon and Christiaensen (2005).

[9] See Jayne, Yamano and Nyoro (2004) and Gregory and Bumb (2006).

[10] See Larson, Anderson and Varangis (2004), and Skees et al. (2005).

There are additional reasons for low fertilizer use tied to knowledge and information hurdles. Several authors note that levels of education are especially low in Africa which slows the dissemination of new ideas and techniques.[11] A related argument is that the institutions charged with dissemination are also weak, partly because of low stocks of human capital and partly due to governance. A second set of arguments are more subtle and focus not on the capacity to learn but on difficulties in discovering appropriate techniques. This argument goes that, because soil and growing conditions are heterogeneous in Africa, an identical technology identically applied can have different outcomes for neighboring households. Consequently, advice offered by extension agents gleaned from nearby field stations can be inappropriate for many farmers. For the same reason, the efficacy of learning by example is limited; instead, farmers must learn through experimentation, which is risky and comes with added costs.

As discussed, the empirical model we develop in the next section is motivated by the presumption that Ethiopian farmers decide on fertilizer input levels in a constrained environment. This distinguishes our model from earlier efforts to measure the determinants of fertilizer demand in Ethiopia. Most empirical studies to date, by relying on tobit-model estimates, implicitly characterize zero-valued observations of fertilizer demand as corner solutions – that is, zero-value outcomes are modeled as though they emerged from a self-truncating process.[12] Alternatively, when farmers who would use fertilizer are additionally constrained by poorly performing markets, an additional process is implied. We return to this topic in the next section.

The Empirical Framework

The starting point for the empirical model is an input demand function, derived from the standard farm household profit maximization conditions via Hotelling's lemma. As discussed, the subsequent choice of an appropriate empirical model depends critically on assumptions about the determinants of zero-value outcomes. In our case, we assume that, in some instances, farmers forgo fertilizer-using techniques because the opportunity costs of doing so are high. But we also allow for instances in which market imperfections further truncate implicit demand. In particular, we include in the estimation of fertilizer demand, an additional step, and we use a set of determinants to control for the potential effects of incomplete markets.[13]

[11] See Sachs et al. (2004)

[12] For example, see studies by Bacha et al (2001), Croppenstedt and Demeke (2003), Fufa and Hassan (2006), Wubeneh and Sanders (2006), and Alem et al (2008) have looked at different variants of this issue in Ethiopia.

[13] The alternative is that zero-use outcomes are voluntary corner-solutions that are optimal from the household's perspective.

The result is panel selection model, which provides estimates of the demand for fertilizer that are adjusted for selection bias [14] In particular, the demand for chemical fertilizer (f_{it}) is specified as:

$$f_{it} = \boldsymbol{\beta}' x_{it} + \varepsilon_{it} + c_i \geq 0,$$

where f_{it} represents chemical fertilizer used in kilograms per hectare, $\boldsymbol{x}_{\mathbf{it}}$ is a vector of variables affecting demand for chemical fertilizer, where c_i is a random effect associated with farm *i*, and $\varepsilon_{it} \sim N(0, \sigma^2)$. In practice, the demand equation is only observed when farmers are not additionally constrained by weak markets and the corresponding selection mechanism is given by

$$z_{it}^* = \boldsymbol{\alpha}' \boldsymbol{w}_{\mathbf{it}} + u_{it} + d_i;\ z_{it} = 1\ (z_{it}^* > 0)$$

and $\boldsymbol{w}_{\mathbf{it}}$ is a vector of variables that describe the completeness of local markets and the abilities of farmers to cope with incomplete markets, where d_i is a random effect associated with farm *i*, and $u_{it} \sim N(0,1)$. The two random errors are potentially correlated with $corr(e, u) = \rho$. The random effects, c_i and d_i, are assumed to be bivariate-normally distributed with zero means and standard deviations, σ_c and σ_d, respectively. The random effects are also potentially correlated with $corr(c, d) = \theta$. A simulated maximum likelihood method is used to estimate the model.[15]

Our estimation strategy follows the parametric approach suggested by Greene (2007), based on efforts by Verbeek (1990), Zabel (1992), Verbeek and Nijman (1992), which we prefer to nonparametric approaches.[16] While there is an advantage to the nonparametric estimators, as they are robust to distributional misspecifications of the correlation between the unobserved effects and observed variables, from a practical perspective, the approach is less useful for policy-motivated research. As Greene (2007: E30-2) emphasizes, the parameters of the selection model are not the slopes of the index function, the implicit behavioral component of the model. Consequently, additional and more detailed assumptions about the underlying functional form and parametric family are still needed to interpret the conditional means and partial effects from the model, which are often key to policy discussions.

Turning to the choice of determinants, the arguments in the selection equation are chosen to capture factors that determine access to chemical fertilizer through markets – that is, factors that increase transaction costs or discourage the entry of intermediaries and factors that allow households to compensate for poorly performing markets. As discussed, market risk, low-moisture climates and remoteness are expected to result

[14] A related double-hurdle model is often used in cross-section studies, including the study by Croppenstedt and Demeke's (2003) mentioned earlier. The applied component is a mixed-model that combines a probit model of adoption with a truncated model of intensity. The focus of the model is on the conditional demand for fertilizer once the adoption hurdle has been cleared (Duan et al. 1984) As Ahn (2004) points out, the distinction between the hurdle and selection models blurs in the case of panel data when the non-zero population varies over time.

[15] LIMDEP 9 is used to estimate the model. See Greene (2007) for greater detail.

[16] See, for example, Kyriazidou (1997), and Honore and Kyriazidou (2000).

in thin fertilizer markets and high transaction costs and we include average rainfall (climate), price variability, and the distance to fertilizer distribution centers to take this into account. While credit and insurance markets are weak in Ethiopia, some farmers do gain access to credit and farmers can take additional meliorative actions before abandoning fertilizer-using techniques. Therefore we include access to credit and a set of arguments (literacy, age and participation in extension programs) that indicate the capacity of the household to overcome weak credit and insurance markets. For the same reason, we also include a measure of wealth: the ownership of a house with a corrugated iron roof. Moreover, the dominant role of state actors in rural Ethiopian fertilizer and credit markets is an important aspect that likely shapes outcomes since fertilizer distribution and credit provision are often handled at a local administrative level. In the face of weak governance and communication systems, holding a position in local government can result in better information or preferential treatment. To test for this, we include a dummy variable to indicate whether the head of the household is a member of the village council.

Input demand is measured in kilos per hectare and we include as determinants farmed area and the relative price of fertilizer. We also include an indicator of whether organic fertilizer is used. Soil moisture is import to the efficacy of fertilizer use and farmers have some scope for adjusting its use as the growing season progresses (Larson and Plessmann, 2009). We therefore include weather outcomes measured relative to long-term averages. In the face of imperfect markets, consumption and production are inseparable and endogenous shadow prices enter into the input demand functions (de Janvry et al., 1991). Nevertheless, the input demand equations can be estimated indirectly by using instruments for the shadow prices (Fafchamps and Quisumbing, 1999). For this reason, we also include a set of household characteristics: household size, wealth, age and education. To account for the cumulative effects of technology adoption, we include a time effect.[17]

Data Sources and Descriptive Statistics

The household data used in our analysis comes from a countrywide panel household survey conducted in 2004 and 2006 by the Ethiopian Economic Association (EEA) and the World Bank. The survey consists of about 2,300 randomly selected households in 115 villages (kebeles) stratified by agro-ecological zone and region to ensure coverage of all the agricultural production systems of the country. After adjusting for missing data, there are data on 2,140 matching households. The first round focused on extension services while the core section was the land certification program during the second round, so there are some differences in the

[17] For a discussion of how adoption rates are expected to spread with time, see Feder and Umali (1993).

questionnaires. Because of missing values, our sample is unbalanced and contains 4,126 observations on 2,104 households.[18]

The survey data was supplemented with district level data on output prices from Ethiopia's Central Statistical Authority and fertilizer prices from the Ministry of Agriculture and Rural Development, Agricultural Marketing Directorate. Data on rainfall for the survey years came from the Ethiopian Meteorological Agency.[19] The climate variable was constructed from average values (1960-90) of historical spatial data prepared by the Climate Research Unit (Mitchell et al. 2002). For each year of the panel, we construct a measure of weather by taking the ratio of average rainfall for the growing season over the thirty-year average for the same period and place.

Consistent with the national figures, the 2006 wave survey data show that the Amhara and Oromia regions have higher proportions of fertilizer user households (61 % and 58%, respectively) followed by SNNP and Tigray regions (57% and 55%, respectively). However, in terms of consumption per hectare of fertilized land, SNNP and Tigray regions exhibit higher fertilizer use with per hectare averages of 153 kg and 144 kg, respectively, followed by Amhara and Oromia regions with per hectare averages of 129 kg and 111 kg, respectively. The lower intensity of fertilizer use in Oromia may be related to the region's soil type[20].

Table 1 indicates that around 68% and 63% of the households in the sample used one or multiple types of fertilizer (DAP, Urea or mix of the two) in 2004 and 2006, respectively. The average fertilizer consumption increased from 42 to 55.7 kilograms per hectare in between the two rounds when both user and non-user households are considered. A similar trend is also observed when user households alone are considered as average consumption has increased from 61 to 88 kilograms per hectare during the same period. At a plot level, average consumption per a hectare of fertilized plot increased from 116 to 167 kilograms per hectare. Though fertilizer use increased significantly, it remained below the recommended 200 kilograms per hectare mark.

As discussed, several factors may explain the low fertilizer adoption rate in Ethiopia. However, even when farmers adopt chemical fertilizers, the application of fertilizer is below recommended rates. The problem is further aggravated by the poor timing of the fertilizer application; a shortage of well-trained agricultural extension workers; and the generally ineffective transmission of the government's research outputs. For instance, while the Ethiopian Agricultural Research Institute recommends the application of urea over two cycles, the 2004 wave of the panel data shows that farmers who apply fertilizer do so all at once

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[18] By design, the survey is meant to capture the diverse geography of Ethiopia, and may not be nationally representative of Ethiopian farmers.

[19] Survey sites were matched with data from the closest weather station.

[20] For instance, the Ethiopian Ministry of Agriculture study recommends a lower dose of fertilizer per hectare (at 150 kg per ha. vs. the usual 200 per ha.) for vertisols soil type with improved Durhum wheat seed type.

and none of the surveyed households applied urea in two cycles. The combined result of low-dose application and non-optimal timing may explain the low response of output for chemical fertilizer, which in turn, further discourages potential adopters.

The structure of fertilizer markets in Ethiopia has constantly changed since the mid-1990s when, following the fall of the Derg regime, the state monopoly on the distribution of fertilizer was lifted. By 1996, 67 private wholesalers and about 2,300 retailers handled roughly two-thirds of the fertilizer market (World Bank, 2006). By the study period, this had changed. By 2004, a combination of companies with potential political affiliation and a public enterprise, the Agricultural Input Supply Corporation, dominated the wholesale market, with cooperatives handling an increased share of the wholesale market by 2006 and fertilizer was distributed to farmers through a combination of extension agents, local governments and cooperatives and some private retailers.[21]

The changing structure of fertilizer markets came as a consequence of a government decision to promote "packets" of high-yielding seeds, fertilizers and extension services. Following a set of successful pilots, the approach was rapidly expanded under Ethiopia's Participatory Demonstration and Extension Training System (PADETS). For the most part, the packets are sold on credit after a 10 to 35 percent down payment (DSA, 2006). Credit is extended through the Commercial Bank of Ethiopia through cooperatives, local authorities and micro-lending institutions, which also handle record keeping and the collection of interest and principal.

Timely and adequate supply of fertilizer is one of the major problems reported by a significant proportion of the households surveyed in the 2004 round. 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 point to high fertilizer price and tight credit repayment schedules as problems that constrain fertilizer use.

Yet, despite the public sector's dominant role, a study by Heisey and Norton (2006) suggests that, on average, the margins between farmgate and import prices for fertilizers in Ethiopia compare well to similarly calculated margins in South Africa and other African economies – although the margins are still high in comparison to Asia or Latin America. The authors speculate that this is because of the implicit subsidy of distributing fertilizer supplies through extension agents and other local institutions. Even so, Mazegbo (2005) notes large regional differences in fertilizer margins, suggesting a diversity in how local markets function.

Credit plays an important role in acquiring fertilizer. In the 2004 survey wave, 61.5% of households received fertilizer on credit, while cash purchases accounted for only 37.7% (table 2). Moreover, the pattern

[21] A 2006 report by the Ethiopian Economic Association/ Ethiopia Policy Research Institute (EEA/EEPRI) estimated that the public sector handled about 70 percent of the retail market.

of credit finance across the different regions is quite skewed. While credit finances more than 80% of purchases in Oromia, shares of credit-purchases drop to 35.7% and 40% in SNNP and Amhara regions, respectively. In Tigray, credit finances around 63% of fertilizer purchases. In terms of access to credit (from all type of sources such as friends, banks, microfinance and cooperatives), more households in Amhara and Oromia have access to credit than households in Tigray and SNNP. The average obtainable credit ceiling is also higher in Oromia and Amhara.

As mentioned, supplying fertilizer and facilitating credit for its acquisition has been an important component of Ethiopia's PADETS program. In the 2004 survey, households were asked if they participated in extension program and how productivity gains from the package compared with the traditional practices. More than 64% of the sampled households participated in the package and 95% of the households found the new technology more profitable than the traditional one. More than 50% of the households responded that production increased by half while 20% of households reported production increase of more than 50%. Only a small proportion of households (7%) felt that the extension package was riskier than the traditional practices and only 11% of the households opted out of the extension package.

Among these, 33% of households reported that a lack of credit was a major reason why they withdrew from the program. That credit would be constrained is perhaps understandable, as 62% of households ran into difficulty repaying the input loan on one or more occasion. The three major reasons for default on the input loans are low yield due to rain failure, low output price and timing of repayment (being forced to repay immediately after harvest when output prices are depressed). The efficacy of fertilizer also depends on land preparation and fertilizer application may be constrained by a lack of essential farm implements. The Ethiopian Agricultural Research Institute best practice guides suggest three to five cycle of pre-harvest land preparation to get the optimal results from fertilizer applications, but 57% of households report that they lack land-preparation tools.

In the 2006 wave of the survey, the share of chemical fertilizers is around 18% of the total value of outputs while the share of all purchased inputs (including expenditures on chemical fertilizer, improved and traditional seeds, hired labor, transportation, rented in oxen and tractor) is around 27%. The figures may be indicative of the profitability of chemical fertilizers and other purchased inputs. However, adoption seems to be lower as only 45% of the cropped area is covered by chemical fertilizer; and the intensity of fertilizer use is on average below the recommended dose of 200 kilograms per hectare.

Empirical Results

Estimation results from the panel selection model are given in Table 3. In general, the model fits well and the parametric values and related statistical test are consistent with the notion that fertilizer markets in Ethiopia are incomplete.[22] At the same time, the model suggests that, when circumstances are favorable, the demand for fertilizer by farmers is sensitive to relative prices and behaves as expected.

Selection Equation

The first three determinants in the selection equation -- household size, the age and state of literacy for the household head – relate to the household's ability and capacity to implement farming techniques that use chemical fertilizers. The results indicate that larger households and households headed by younger and literate farmers are more likely to use fertilizers. The negative effect of age may be due to a reluctance to accept new technologies and lack of technical capability to use chemical fertilizers effectively. In addition, for chemical fertilizers to give the maximum return, intensive pre-harvest land preparation and keeping the optimal application time are required. Advancing age may limit the ability of farmers to fulfill these essential and physically demanding requirements in the face of weak labor market. In a related way, the positive effect of household size may be the consequence of a more abundant supply of family labor. In addition, large families may adopt highly productive inputs to fulfill higher food requirement in cases where expanding land holding is restricted by imperfect or missing land markets. (We return to this topic below.) The negative effect of illiteracy may also be the combination of different effects. One channel is that illiterate farmers may not have the minimum required knowhow for effective application of chemical fertilizer. The other possible channel, suggested by Pitt and Sumodiningrat (1991) is that illiterate farmers are more risk averse and, consequently, less willing to take on the additional risks associated with fertilizer use.

The next set of determinants indicates that better access to fertilizer markets and supporting services increases the probability of adopting chemical fertilizer. Access to credit, participation in the extension program and proximity to fertilizer distribution centers all increase the probability of adopting chemical fertilizer in the estimated model. As discussed, fertilizer markets are more likely to be incomplete in dryer climates that disfavor fertilizer use and in areas where relative prices are more volatile. The estimation results are consistent with this view as the probability of adoption rises with average rainfall during the growing season and falls with price volatility.

Results associated with the last two determinants are consistent with the notion that wealth and social capital or authority help farmers mitigate incomplete credit and insurance markets. Greater wealth is expected to increase the credit-worthiness of farmers and also allow farmers to self-finance. Wealthier farmers are also better able to self-insure against temporary shortfalls in income.[23] Our results are consistent with these expectations and suggest that wealthier households are more likely to adopt chemical fertilizers.

[22] On a technical note, errors associated with two components of the model are correlated, as expected. See the lower panel of table 3.

[23] There is some empirical evidence that wealthier households tend to avoid riskier inputs (Pitt and Sumodiningrat, 1991). In our study, this does not appear to be a dominant effect.

The selection equation also indicates that being in a position of local authority increases the probability of adopting fertilizer-using techniques. Because fertilizer and credit supplies are channeled through a variety of local public and cooperative agencies, holding political power at the local administrative unit may facilitate access to credit and fertilizer. For one, politically active households may have better information on state-sponsored programs. As discussed, to obtain fertilizer credit, farmers are required to pay a certain percentage of the fertilizer cost as down payment, but the size of the down payment is not uniform. For example, in the Oromiyo region, the down payment is generally 25-30 percent, but can run as high as 60 percent and some farmers receive loans without a down payment. Discretion is given to local agencies, so the system is potentially open to local influence. (DSA 2006). At the same time, farmers that are politically active may also have unobservable entrepreneurial characteristics that make them more likely to adopt new technologies and also adopt leadership roles. Our result may capture any or all of these channels.

Demand for Chemical Fertilizer

The middle panel of table 3 gives the parameters of the fertilizer demand equation, adjusted for selection. The first result is that Ethiopian farmers in the sample were sensitive to the price of fertilizer relative to output prices. This is consistent with theory and also consistent with literature suggesting that, by raising fertilizer costs and reducing farm-gate prices for surplus production, high transport costs dampen the use of fertilizers by African farmers. The results also indicate that farmers who use manure also use more chemical fertilizer. To some extent, organic and chemical fertilizers are substitutes, since both are sources of plant nutrients. However, it is also true that the efficacy of chemical fertilizers depends on the organic content of the soils. In Africa, where soils are often depleted, consistent practices of fallowing or using manure are required to build up the soils carbon content, resulting in a complementary relationship between the two.[24] Our analysis suggests this later relationship is dominant in our sample.

The results also suggest a statistically significant and negative association between the intensity of fertilizer and farm size. This is contrary to the positive correlation between land size and fertilizer use in Feder, Just and Zilberman (1985), but consistent with the results reported in Croppenstedt and Demeke (2003) in the case of Ethiopia and Nkonya et al. (1997) in the case of Tanzania. This may have to do with a willingness by farmers with smaller holdings to invest greater time and effort into their limited holdings. In addition, Nkonya et al. (1997) suggest that farmers with larger holding sometimes hedge risks by applying on a smaller proportion of their land, thereby reducing average application rates.

Parameter estimates associated with age and the literacy of the household head, which were significant in the adoption of fertilizer-use, were not statistically significant determinants of the intensity of

[24] Marenya nd Barrett (2009) and Matsumoto and Yamano (2009) provide evidence that the organic content of soils, which can be built up through the application of organic fertilizer, increases the efficacy of chemical fertilizers.

fertilizer use.[25] In the case of household size, this suggests that the channel through which household size affects adoption has more to do with food demand that weak labor markets. From a technical perspective, excluding these variable from the model does not materially affect the parameters of the remaining determinants.[26] In contrast, literacy does have a positive impact on fertilizer use.

As discussed, wealth can mitigate weaknesses in credit and insurance markets. Separate from the capacity to take-on risk, wealth may also be associated with a greater preference for risk. Consistent with these arguments, the parameter on wealth in the demand equation is positive and statistically significant, as it was in the adoption equation. In general, fertilizer applications are made before weather outcomes are known; although farmers can make some adjustments when fertilizer is applied in a series of doses. As discussed, this latter practice is not common in Ethiopia and the results suggest that, although climate is an important determinant of whether fertilizer-using practices are adopted, contemporaneous weather outcomes do not affect fertilizer demand in a statistically measureable way. And finally, the time effect estimates suggests that fertilizer demand increased between the first and second waves, even after adjusting for changes in other determinants. This provides indirect evidence of a positive trend in the adoption of fertilizer-using technologies that is consistent with government efforts to promote more productive technologies.

Conclusion

Cereal yields and fertilizer use are low in Ethiopia relative to other regions and there is a widely expressed view that a significant change in Ethiopian agriculture is impossible without a significant increase in the use of fertilizers. Moreover, because supplies of organic fertilizer and the scope for increased fallowing are limited in Ethiopia, any significant growth in fertilizer use will depend on an increase in the application of chemical fertilizers. Even though research from field studies and pilot programs in Ethiopia shows that the economic returns to chemical fertilizer are sometimes large relative to its cost; the application rates are nonetheless low. Based on a panel household data from 2004 and 2006, this paper examines the role of missing and imperfect markets that affects farmer choices about chemical fertilizer applications in Ethiopia.

Taken together, the results suggest that fertilizer markets are not altogether absent in rural Ethiopia and, for some farmers, work as expected. At the same time, the modeling results provide evidence that high transport costs, limitations in complementary markets for credit and insurance, adverse climate and illiteracy all conspire to limit the adoption of chemical fertilizers in Ethiopia. Moreover, the combination of factors that promote or impede effective fertilizer markets differs among locations, making it difficult to find a single production technology that is uniformly profitable. One implication is that inconsistencies can be expected between field studies and pilots finding large returns to the use of fertilizers in Ethiopia and studies finding

[25] Nkonya et al (1997) report a similar finding.
[26] See table 1 of the supplemental annex.

that fertilizer applications are uneconomical since market conditions are crop and place dependent. This in turn has consequences for incomes, food security and the sustainability of soils.

The results suggest that households with greater wealth, human capital and greater authority can apply those assets to overcome hurdles that stand in the way of making greater use of fertilizers. The finding offers some encouragement, but it also implies a self-enforcing link between low agricultural productivity and poverty, since low-asset households are less able to compensate for weaknesses in Ethiopian fertilizer markets. The study suggests that the provision of extension services can be effective in helping households participate in fertilizer markets and that lowering transport costs can improve the intensity of fertilizer use in Ethiopia by lowering the cost of fertilizer and boosting the value of outputs at the farmgate.

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Tables

Table 1: Sample statistics on output and fertilizer use

	2004	2006
Value of Output in Birr per ha	1,405.90	1,807.70
Chemical Fertilizer in Kg	42.00	55.70
Manure in Kg	229.00	549.30
Chemical Fertilizer in Kg per fertilized hectare	116.00	167.00
Percentage of households using:		
Chemical Fertilizer	68.50	63.30
Manure	28.10	58.00
Improved Seeds	35.60	30.10

Table 2: Method of fertilizer acquisition in 2004, (% of total)

	Organic Fertilizer	Chemical Fertilizer
Cash	10.3	37.7
Credit	10.2	61.5
Own (Left over)	..	0.1
Land owner	13.5	0.1
For free	9.7	0.6
Own animal dung	56.4	..

Table 3: Estimation results

Selection equation parameters	Coefficient	Std. error
Household size	0.103[a]	0.012
Age of household head	-0.007[a]	0.002
Education of household head	1.132[a]	0.212
Credit	0.336[a]	0.062
Extension	0.881[a]	0.059
Fertilizer distribution center	0.253[a]	0.061
Climate	0.002[a]	0.000
Price risk	-0.081[b]	0.039
Wealth	0.122[b]	0.059
Village Council membership	0.412[a]	0.085
Selection-corrected regression parameters		
Relative price	-14.272[c]	7.816
Use of organic fertilizer	9.916[c]	5.867
Area	-0.897[a]	0.159
Household size	0.021	1.131
Age of household head	0.078	0.215
Education of household head	24.532[b]	11.313
Wealth	9.736[c]	5.486
Weather	-14.246	9.399
Time effect	39.847[a]	7.210
Error structure		
Disturbance standard deviation, σ	0.008	0.641
Correlation between regression and probit, ρ	-0.160[a]	0.043

Note: The superscripts a, b, and c indicate significance at the 1, 5, and 10 percent level, respectively. The model was estimated using LIMDEP version 9.0.

Annex supplemental table

Annex Table 1: Estimation results from the base model and alternative model

	Base model		**Alternative model**	
	Coefficient	Std. error	Coefficient	Std. error
Selection equation parameters				
Household size	0.103[a]	0.012	0.101[a]	0.012
Age of household head	-0.007[a]	0.002	-0.007[a]	0.002
Literacy of household head	1.132[a]	0.212	1.049[a]	0.210
Credit	0.336[a]	0.062	0.338[a]	0.062
Extension	0.881[a]	0.059	0.866[a]	0.059
Fertilizer distribution center	0.253[a]	0.061	0.268[a]	0.061
Climate	0.002[a]	0.000	0.002[a]	0.000
Price risk	-0.081[b]	0.039	-0.084[b]	0.032
Wealth	0.122[b]	0.059	0.104[c]	0.059
Village Council membership	0.412[a]	0.085	0.422[a]	0.085
Selection-corrected regression parameters				
Relative price	-14.272[c]	7.816	-14.693[b]	7.182
Use of organic fertilizer	9.916[c]	5.867	9.948[c]	5.875
Area	-0.897[a]	0.159	-0.895[a]	0.158
Household size	0.021	1.131		
Age of household head	0.078	0.215		
Literacy of household head	24.532[b]	11.313	23.473[b]	11.242
Wealth	9.736[c]	5.486	9.944[c]	5.366
Weather	-14.246	9.399	-13.889	9.320
Time effect	39.847[a]	7.210	40.377[a]	6.936
Error structure				
Disturbance standard deviation, σ	0.008	0.641	0.008	0.566
Correlation between regression and probit, ρ	-0.160[a]	0.043	-0.170[a]	0.041

Note: The superscripts a, b, and c indicate significance at the 1, 5, and 10 percent level, respectively. The model was estimated using LIMDEP version 9.0.