INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
sustainable solutions for ending hunger and poverty
Supported by the CGIAR

ETHIOPIAN DEVELOPMENT RESEARCH INSTITUTE

ESSP II Working Paper 31

Cereal Production and Technology Adoption in Ethiopia

Bingxin Yu, Alejandro Nin-Pratt, José Funes, and Sinafikeh Asrat Gemessa

Development Strategy and Governance Division, International Food Policy Research Institute

Ethiopia Strategy Support Program II (ESSP II)

ESSP II Working Paper 31

November 2011

IFPRI-ADDIS ABABA
P.O. Box 5689
Addis Ababa, Ethiopia
Tel: +251-11-646-2921
Fax: +251-11-646-2318
E-mail: ifpri-addis@cgiar.org
http://essp.ifpri.info/

IFPRI HEADQUARTERS
International Food Policy Research Institute
2033 K Street, NW • Washington, DC 20006-1002
USA
Tel: +1-202-862-5600
Skype: IFPRIhomeoffice
Fax: +1-202-467-4439
E-mail: ifpri@cgiar.org
http://www.ifpri.org

THE ETHIOPIA STRATEGY SUPPORT PROGRAM II (ESSP II) WORKING PAPERS

ABOUT ESSP II

The Ethiopia Strategy Support Program II is an initiative to strengthen evidence-based policymaking in Ethiopia in the areas of rural and agricultural development. Facilitated by the International Food Policy Research Institute (IFPRI), ESSP II works closely with the government of Ethiopia, the Ethiopian Development Research Institute (EDRI), and other development partners to provide information relevant for the design and implementation of Ethiopia's agricultural and rural development strategies. For more information, see http://www.ifpri.org/book-757/ourwork/program/ethiopia-strategy-support-program or http://essp.ifpri.info/ or http://www.edri.org.et/.

ABOUT THESE WORKING PAPERS

The Ethiopia Strategy Support Program II (ESSP II) Working Papers contain preliminary material and research results from IFPRI and/or its partners in Ethiopia. The papers are not subject to a formal peer review. They are circulated in order to stimulate discussion and critical comment. The opinions are those of the authors and do not necessarily reflect those of their home institutions or supporting organizations.

This paper was previously published as IFPRI Discussion Paper 01131, *Cereal Production and Technology Adoption in Ethiopia* by Bingxin Yu, Alejandro Nin-Pratt, José Funes, and Sinafikeh Asrat Gemessa.

About the Author(s)

Bingxin Yu: Research Fellow, Development Strategy and Governance Division, International Food Policy Research Institute, b.yu@cgiar.org

Alejandro Nin-Pratt, Research Fellow, Development Strategy and Governance Division International Food Policy Research Institute, a.ninpratt@cgiar.org

José Funes, Research Analyst, Development Strategy and Governance Division International Food Policy Research Institute, j.funes@cgiar.org

Sinafikeh Asrat Gemessa: Department of Public Administration in International Development, Harvard Kennedy School of Government, sinafikey@gmail.com

Cereal Production and Technology Adoption in Ethiopia

Bingxin Yu, Alejandro Nin-Pratt, José Funes,
And Sinafikeh Asrat Gemessa

Development Strategy and Governance Division,
International Food Policy Research Institute

Table of Contents

List of Tables

List of Figures

Abstract

The Ethiopian government has been promoting a package-driven extension that combines credit, fertilizers, improved seeds, and better management practices. This approach has reached almost all farming communities, representing about 2 percent of agricultural gross domestic product in recent years. This paper is the first to look at the extent and determinants of the adoption of the fertilizer-seed technology package promoted in Ethiopia using nationally representative data from the Central Statistical Agency of Ethiopia. We estimate a double hurdle model of fertilizer use for four major cereal crops: barley, maize, teff, and wheat. Since maize is the only crop that exhibits considerable adoption of improved seed, we estimate a similar model for the adoption of improved seed in maize production. We find that access to fertilizer and seed is related to access to extension services and that production specialization together with wealth play a major role in explaining crop area under fertilizer and improved seed. One of the most important factors behind the limited adoption of the technological package is the inefficiency in the use of inputs, which implies that changes are needed in the seed and fertilizer systems and in the priorities of the extension service to promote more efficient use of inputs and to accommodate risks associated with agricultural production, especially among small and poor households.

1. Introduction

As one of the poorest countries in the world, Ethiopia's agricultural sector accounts for about 40 percent of national gross domestic product (GDP), 90 percent of exports, and 85 percent of employment. The majority (90 percent) of the poor rely on agriculture for their livelihood, mainly on crop and livestock production. In 2007, 70 percent of all land under crops was used for cereal production (CSA 2009).

The economic growth strategy formulated by the government in 1991 places high priority on accelerating agricultural growth to achieve food security and poverty alleviation. A core goal of this strategy was to increase cereal yields by focusing on technological packages that combined credit, fertilizers, improved seeds, and better management practices. The Participatory Demonstration and Training Extension System (PADETES) was started in 1994/95 and in its early stages focused on wheat, maize, and teff; it expanded to other crops in later years. The extensive data from millions of demonstrations carried out through PADETES indicated that the adoption of seed-fertilizer technologies could more than double cereal yields and would be profitable to farmers in moisture-reliant areas (Howard et al. 2003).

PADETES became the vehicle for the extension program, emphasizing the development and distribution of packages of seeds, fertilizer, credit, and training. This package-driven extension approach has been implemented on a large scale and has reached virtually all farming communities in Ethiopia, representing a significant public investment in extension (US$50 million dollars annually or 2 percent of agricultural GDP in recent years), four to five times the investment in agricultural research.

The impacts of the implemented policies have been mixed, with increased use of fertilizer but poor productivity growth (World Bank 2006), and in general with no major benefits for consumers as food prices do not show declining patterns. Byerlee et al. (2007) concluded that some of the major factors affecting the results of the intensification program are low technical efficiency in the use of fertilizer, poor performance of the extension service, shortcomings in seed quality and timeliness of seed delivery, promotion of regionally inefficient allocation of fertilizer, no emergence of private-sector retailers negatively affected by the government's input distribution tied to credit, and the generation of an unleveled playing field in the rural finance sector by the guaranteed loan program with below-market interest rates.

In this paper we examine the level and determinants of adoption of the promoted technology. Specifically, the objectives of this study are to assess the extent of adoption of the fertilizer-seed technology package promoted by PADETES since 1996, and to determine the main economic factors affecting utilization of modern inputs. Preliminary policy implications for increasing the use of inputs and accelerate output and productivity growth in crop production are also derived.

This paper contributes to the literature of technology adoption in several aspects. First, it features the sequential process of decisionmaking in technology adoption by separating the decision to adopt fertilizer (or improved seed) and the decision about the quantity of input use. Second, it addresses the endogeneity of extension service to improve our understanding of the effectiveness of PADETES. This paper also estimates average partial effect (APE) for determinants of technology adoption, allowing us to examine the unconditional effect of factors that influence the adoption process. This indicator is especially relevant when there are observations with zero values for input quantity. Finally, to our knowledge, this is the first attempt to analyze technology adoption in Ethiopia using nationally representative data based on Agricultural Sample Surveys from the Central Statistical Agency (CSA) (various years). In addition to traditional socioeconomic indicators, we also incorporate the spatial distribution of biophysical constraints and market accessibility in the study to take into account the impact of local agronomic and development conditions on technology adoption. Data were available at the plot level annually and provide rich details on area, production, and input use for many crops in Ethiopia's agriculture.

The rest of the paper is organized as follows. In Section 2 we present evidence of changes in the use of fertilizer and improved seed by comparing fertilizer and improved seed use over the period 2003–06 and also show spatial patterns of technology diffusion. Section 3 presents the conceptual framework to explain adoption behavior. Analytic model and econometric considerations are delineated in Section 4. Section 5 derives policy implications for Ethiopia's agricultural sector and Section 6 concludes.

2. Evidence on technology adoption in Ethiopia's cereal production

2.1. Brief characterization of cereal production

Table 2.1 presents a summary of area, production, and yields of cereals in main production regions in Ethiopia in 2003/04 and 2007/08. Total cereal production was 13.6 million tons1 in 2007/08, an increase of 4.8 million tons compared to production in 2003/04. Total area allocated to cereals also expanded by 27 percent over the same period. Average cereal yield reached 1.6 tons per hectare in 2007/08, exhibiting a 22 percent growth over five years.

In 2007/08, the main cereal according to land use was teff (30 percent of total cereal land), followed by maize (20 percent), sorghum (18 percent), and wheat (16 percent). In terms of volume, maize ranked first with 3.8 million tons of output, followed by teff, sorghum, and wheat with production of 3.0, 2.7, and 2.3 million tons, respectively. The difference in area and output ranking indicates that maize yields are higher than yields of other cereals (2.1 tons per hectare compared to 1.4 for barley and 1.2 for teff). As discussed by Seyoum Taffesse (2009), Ethiopia's yield levels are lower than the average yield in Least Developed Countries defined by the United Nations, although they are higher than the average yield in eastern Africa.

Cereal cultivation is highly concentrated geographically. Almost 80 percent of total area under cereals is in the Amhara and Oromia regions to the northwest, west, southwest, and south of the capital, Addis Ababa (see Figure 2.1). This area includes a diverse set of conditions for agricultural production. Spatial conditions for production and market access have been discussed elsewhere (see Diao and Nin Pratt 2005; Tadesse et al. 2006) and we refer the reader to those materials.

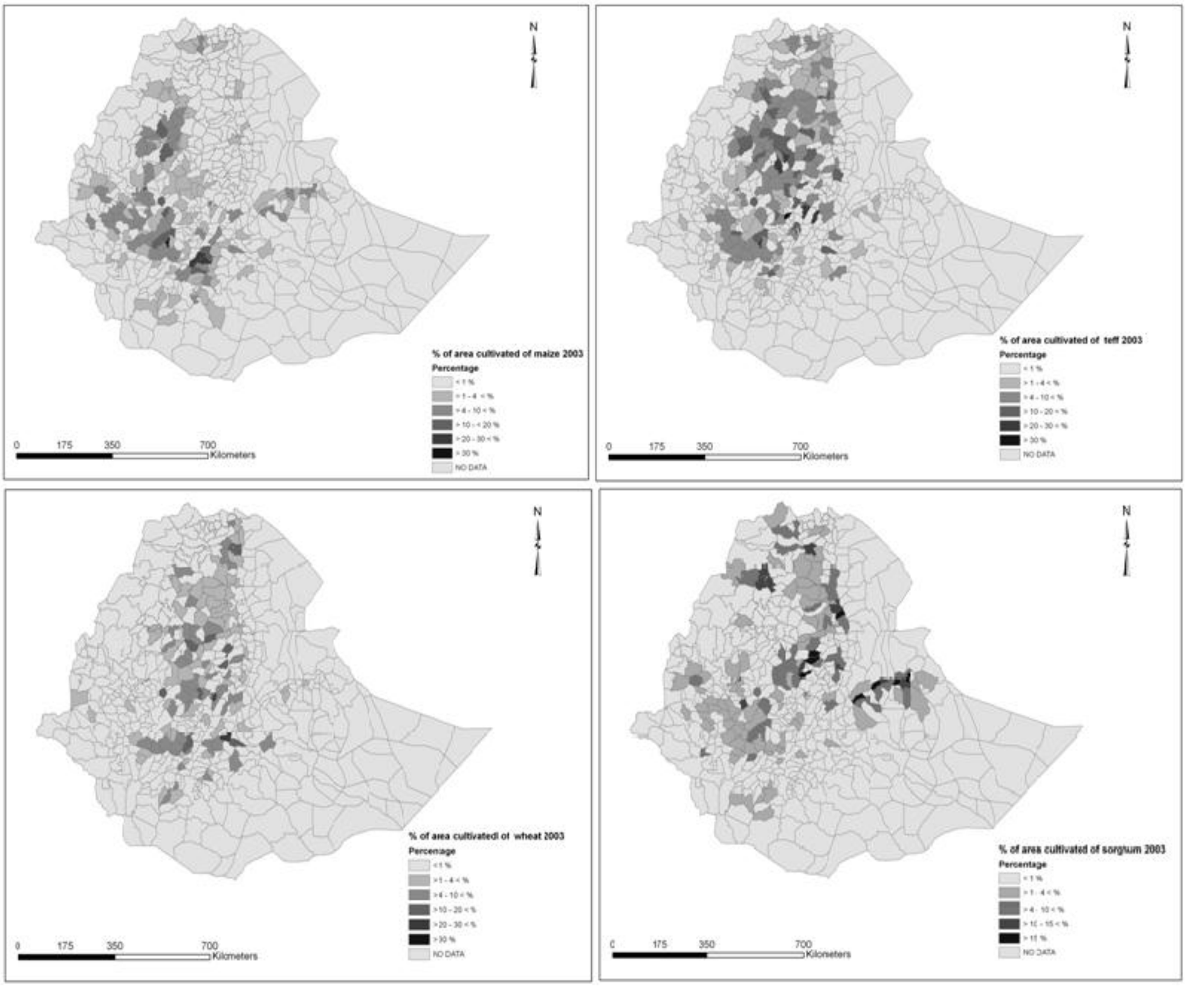
[1] Weight is measured in metric tons.

Table 2.1. Area, production and yields of cereals in Ethiopia, 2003/04 and 2007/08

	2003/04				2007/08				Growth rate (%)			
	Area	Production	Yield	Area share	Area	Production	Yield	Area share	Area	Production	Yield	Area share
Cereal crop	000 hectares	000 tons	Tons/ha	%	000 hectares	000 tons	Tons/ha	%				
Barley	911	1,071	1.2	13.4	985	1,355	1.4	11.4	8.1	26.5	17.0	-14.9
Maize	1,300	2,455	1.9	19.1	1,767	3,750	2.1	20.4	35.9	52.7	12.3	6.8
Millet	303	304	1.0	4.5	399	538	1.3	4.6	31.7	77.0	34.4	2.2
Sorghum	1,242	1,695	1.4	18.2	1,534	2,659	1.7	17.7	23.5	56.9	27.0	-2.7
Teff	1,985	1,672	0.8	29.1	2,565	2,993	1.2	29.6	29.2	79.0	38.6	1.7
Wheat	1,075	1,589	1.5	15.8	1,425	2,314	1.6	16.4	32.6	45.6	10.0	3.8
Other	35	44	1.3	0.5	55	108	2.0	0.6	57.1	145.5	56.1	20.0
Total Cereal	***6,816***	***8,786***	***1.3***	***100***	***8,675***	***13,609***	***1.6***	***100***	***27.3***	***54.9***	***21.7***	

Source: Author's calculation using CSA Agricultural Sample Survey data (various years).

Figure 2.1. Importance of different cereals measured as share of the crop cultivated area in total woreda area (in percentage)



Source: Authors' calculation using CSA Agricultural Sample Survey data (various years).

2.2. Evidence on technology adoption and input use in cereal production

The adoption of the promoted technology package in cereals is measured as the area under cereal production using chemical fertilizer or improved seed or both. Between 2003/04 and 2007/08, the area for four of the major cereal crops (barley, maize, teff, and wheat) under the promoted technologies (fertilizer or seed or both) increased from 1.5 to 1.7 million hectares, growing at 4 percent annually (Table 2.2). The adoption rate of the new technology increased from 42 percent in 2003 to 48.5 percent in 2006 then fell below 47 percent in 2007.

The adoption of the promoted package of fertilizer and improved seed has been limited. Based on a panel of 270 woredas (districts) from Central Statistical Agency, we find that the area jointly using improved seed and chemical fertilizer has oscillated around 220,000 hectares for four major cereal crops, accounting for only 6 percent of crop area. The use of fertilizer combined with local seed is the main mode of modern technology adoption; its land share increased substantially from 35 percent in 2003/04 to 41 percent in 2007/08. Farming with improved seed but not using chemical fertilizer is not common. On the other hand, traditional production practice of using local seed but no fertilizer is still prevalent in more than half of the cereal land, surpassing the combination of all area under modern technology.

Table 2.2. Area, production, and yields of cereals using modern inputs or traditional technology

	Total area (000 hectare)				Share in crop area (%)				Growth
Crop and technology	2003	2004	2006	2007	2003	2004	2006	2007	rate (%)
Barley									
Fertilizer and improved seed	0.8	1.8	0.9	1.2	0.1	0.3	0.1	0.2	10.7
Fertilizer and local seed	145.6	164.4	173	140.6	25.8	25.6	27.3	26.6	-0.9
No fertilizer and improved seed	1.2	2.1	0.1	0.2	0.2	0.3	0	0	-36.1
No fertilizer and local seed	415.6	474.2	459	386.8	73.8	73.8	72.5	73.1	-1.8
Total	563.1	642.5	632.9	528.9	100	100	100	100	-1.6
Maize									
Fertilizer and improved seed	197.2	158.1	188.9	192.2	23.4	17.7	17.7	21.6	-0.6
Fertilizer and local seed	99.5	124.6	211.2	146.3	11.8	13.9	19.7	16.4	10.1
No fertilizer and improved seed	10.7	9.5	9.9	5	1.3	1.1	0.9	0.6	-17.3
No fertilizer and local seed	536.1	601.6	660.1	547.9	63.6	67.3	61.7	61.5	0.5
Total	843.5	893.8	1070.2	891.3	100	100	100	100	1.4
Teff									
Fertilizer and improved seed	3.7	7.7	8.2	9.7	0.3	0.5	0.5	0.6	27.2
Fertilizer and local seed	634.2	705	902.2	821.4	45.2	47.2	54.4	53.5	6.7
No fertilizer and improved seed	4.7	3.7	2.1	2.2	0.3	0.2	0.1	0.1	-17.3
No fertilizer and local seed	761.4	778.7	745.8	701.7	54.2	52.1	45	45.7	-2.0
Total	1404	1495	1658.3	1535	100	100	100	100	2.3
Wheat									
Fertilizer and improved seed	24.9	28.3	22.5	14.1	3.7	3.4	2.6	2	-13.3
Fertilizer and local seed	341.6	418.7	533	379.9	50.1	50.4	60.6	53.8	2.7
No fertilizer and improved seed	5.8	5.3	4.2	6.1	0.9	0.6	0.5	0.9	1.3
No fertilizer and local seed	308.9	379	320.3	305.5	45.4	45.6	36.4	43.3	-0.3
Total	681.2	831.3	880	705.7	100	100	100	100	0.9
4 major cereals									
Fertilizer and improved seed	227	196	221	217	6.5	5.1	5.2	5.9	-1.1
Fertilizer and local seed	1,221	1,413	1,819	1,488	35.0	36.6	42.9	40.7	5.1
No fertilizer and improved seed	22	21	16	14	0.6	0.5	0.4	0.4	-11.9
No fertilizer and local seed	2,022	2,234	2,185	1,942	57.9	57.8	51.5	53.0	-1.0
Total	3,492	3,863	4,241	3,661	100.0	100.0	100.0	100.0	1.2

Source: Author’s calculation using CSA Agricultural Sample Survey data (various years).

The detailed breakdown of crop cultivation area by input combinations indicates that the only crop with significant adoption of improved seed is maize. The combined use of fertilizer and improved seed represents about 22 percent of total area of maize in 2007/08. At less than 2 percent, this ratio is marginal for other crops that show a significant area using fertilizer at the same time, used with either improved seed or local seed. More than 50 percent of crops planted with teff and wheat and 40 percent with maize used fertilizer during the period. Barley shows the lowest levels of fertilizer adoption with only 27 percent of its area using fertilizer. Traditional farming practice of using local seed but no chemical fertilizer remains the dominant system in barley (73 percent of land), followed by maize (62 percent), teff (56 percent), and wheat (43 percent) in 2007/08.

We conclude that promotion of the new technologies resulted in an increased use of chemical fertilizer. Conversely, the combined use of fertilizer and improved seed, normally the recommended technical package to take advantage of the higher response of improved varieties to fertilizer, is not applied in most cereal crops. Our results show that the only significant use of fertilizer and improved seed package occurs in maize production, where about one-fifth of maize area was under modern input package in 2007.

2.3. Data, variables, and main factors explaining technology adoption in cereal production

We compiled data from CSA annual Agricultural Sample Surveys conducted in four years: 2003/04, 2004/05, 2006/07, 2007/08, covering all rural parts of Ethiopia. The survey includes agricultural practice at plot level and agricultural holder characteristics. This database is complemented by spatial information that allows the inclusion of variables reflecting heterogeneity in the quality and availability of natural resources, demographic distribution, infrastructure, and market access.

Variables that could potentially affect adoption include plot characteristics, access to agricultural services, holder and household characteristics, resources available to the farmer, local adoption patterns, and reliance on the crop. Table 2.3 presents descriptive statistics for these variables. We also include factors affecting input supply at the woreda level, such as distance to the market, road and population density, and crop suitability, assuming these supply-side constraints may affect a farmer's decision to adopt but not affect the demand. Descriptive statistics are reported by fertilizer usage for four major cereal crops (barley, maize, teff, and wheat). Since improved seed is mostly observed for maize production, we also include improved maize seed information in the far right column of the table.

In summary, Table 2.3 shows substantial differences between technology adopters and nonadopters. Compared to nonadopters, the adopters report larger plot size and higher yields; they are more specialized; they show higher use of pesticides and herbicides; they are younger, more educated, more experienced, and wealthier than nonadopters (more oxen, crop fields, and larger cereal area); they have better access to extension, credit, and advisory services; and they have larger household size. There are also differences in the spatial location of adopters and nonadopters. Adopters tend to have better market access and improved infrastructure (higher road density). They are located in regions with higher population density and better natural endowments (crop suitability), and they live in woredas where technology has disseminated broadly.

Table 2.3. Descriptive statistics of adopters and nonadopters of modern technology by crop and input use

	Chemical fertilizer								Improved seed	
	Barley		Teff		Wheat		Maize		Maize	
	Non-adopter	Adopter	Non-adopter	Adopter	Non-adopter	Adopter	Non-adopter	Adopter	Non-adopter	Adopter
Plot level										
Plot area (ha)	0.12	0.16	0.21	0.27	0.14	0.24	0.10	0.18	0.11	0.22
Plot yield (ton/ha)	1.09	1.27	0.90	1.00	1.25	1.60	1.66	2.05	1.68	2.20
Extension (yes = 1)	0.08	0.31	0.07	0.27	0.10	0.29	0.05	0.55	0.08	0.75
Irrigation (yes = 1)	0.01	0.01	0.01	0.00	0.01	0.01	0.03	0.02	0.03	0.01
Improved seed (yes = 1)	0.00	0.01	0.00	0.01	0.01	0.05	0.01	0.44		
Pesticide and herbicide (yes = 1)	0.02	0.12	0.06	0.14	0.05	0.18	0.01	0.02	0.01	0.01
Holder level										
Gender (male = 1)	0.85	0.84	0.88	0.87	0.86	0.85	0.83	0.87	0.83	0.89
Age	45.5	44.7	43.3	42.9	45.1	43.7	43.3	41.3	43.1	41.1
Education grade	2.1	2.8	2.2	2.8	2.3	3.0	2.4	2.8	2.4	3.0
Credit (yes = 1)	0.21	0.41	0.18	0.39	0.21	0.38	0.18	0.37	0.19	0.42
Advisory service (yes = 1)	0.47	0.51	0.45	0.54	0.47	0.50	0.38	0.58	0.39	0.67
Number of oxen	1.2	1.3	1.3	1.5	1.2	1.4	1.1	1.2	1.1	1.4
Household level										
Household size	5.37	5.82	5.31	5.66	5.36	5.76	5.28	5.68	5.31	5.75
Cereal area (ha)	0.82	1.03	0.93	1.19	0.86	1.14	0.78	0.95	0.78	1.06
Crop land using fertilizer (%)	15.5	84.0	8.9	76.7	12.7	81.8	18.8	74.6	15.5	84.0
Woreda level										
Market access (minutes)	258	230	261	239	257	233	263	248	264	242
Road density (km/km2)	30.8	34.8	29.5	31.6	30.5	34.2	29.3	32.4	29.3	33.5
Population density (persons/km2)	199	221	177	194	193	223	193	213	193	216
Area share of highly suitable land (%)	0.13	0.19	0.29	0.32	0.2	0.2	0.25	0.29	0.25	0.33
Crop land using fertilizer (%)	20.3	37.2	39.2	51.7	36.3	55.4	22.0	31.2		

Source: Author's calculation using CSA Agricultural Sample Survey data (various years)

2.4. Spatial patterns of technology adoption

There are substantial regional variations in the adoption of improved technology (Table 2.4). The spatial distribution of fertilizer use varies by crop, although there is also a significant overlap of zones across the different crops. In general, most of the area under fertilizer is concentrated in four main locations that have suitable natural resources for production and roads linking major cities in different zones.

Table 2.4. Share of land under improved technology in total area by crop in different zones 2003/04–2007/08 (in percentage)

Region	Zone	Maize	Teff	Wheat	Barley
Addis Ababa	1406			0.9	
Amhara	Awi	7.3	3.8		
	East Gojjam	5.0	16.2	7.4	4.8
	North Gonder		3.1		
	North Shewa		4	2.2	
	North Wello			0.8	
	South Gonder	5.1	1.2	0.6	3.0
	South Wello		1.5	5.6	
	West Gojjam	15.7	5.5	1.2	5.2
	Amhara Total	33.1	35.3	17.8	13.0
Oromia	Arsi		1.5	6.9	5.5
	Bale				1.7
	East Shewa		3.4	2.2	
	East Wellega	6.3	2.3		
	Horo Gudru Wellega	3.1			
	Jimma	12.6	8.1		
	Kelem Wellega		5.7		
	North Shewa/Oromia			3.5	
	Southwest Shewa			1.4	1.7
	West Arsi	9.1		2.8	13.1
	West Shewa	4.3	7.5	12	28.6
	Oromia Total	35.4	28.5	28.8	50.6
SNNP	Sidama	2.6			
	Hadiya			2.9	
	Wolayita		1.3		
	SNNP Total	2.6	1.3	2.9	0
Tigray	Central Tigray		1.1		1.8
	Eastern Tigray			1.1	4.7
	Northwestern Tigray		1.2		
	Southern Tigray			1.9	8.5
	Tigray Total	0	2.3	3	15
Subtotal of 4 regions		71.1	67.6	53.3	78.6
Other regions		28.9	32.4	46.7	21.4
Total		100	100	100	100

Source: Author's calculation using CSA Agricultural Sample Survey data (various years).

The first of these locations corresponds to the zones of South Gonder, Awi, and West and East Gojjam in the Amhara region. These zones have a high proportion of suitable land for production of most cereals and are crossed by the road that links the capital city, Addis Ababa, with Debre Markos, Bahir Dar, and Gonder. East Wellega in Oromia has suitable resources for the production of maize and teff, and is also linked to Addis Ababa by the main road going from the capital to the west. Another location that concentrates a significant share of the total area under fertilizer includes Jimma and West Shewa in Oromia. These zones are linked through a main road that goes from the capital to the city of Jimma in the southwest. The last major area sharing a significant proportion of total cereal area under fertilizer includes Arsi and East Shewa in Oromia going as far as Sidama in SNNP (Southern Nations, Nationalities and Peoples). This is another major corridor connecting Addis Ababa with Nazret to the east, and Assela and Awasa to the south.

The spatial distribution of the area under fertilizer between these main locations varies by crop. Maize area using fertilizer is concentrated in West Gojjam, Awi, East Gojjam, and South Gonder in Amhara; East Wellega, Jimma, and Arsi in Oromia. A similar spatial pattern can be found for teff, and some differences with this pattern are evident in wheat and barley. For wheat, most of the area under fertilizer can be found in zones around Addis Ababa: East Gojjam, South Wello, and North Shewa in Amhara, and North, West, and East Shewa and Arsi in Oromia. Finally, barley production using fertilizer can be found in the zones in Amhara located between Bahir Dar and Addis Ababa to the northwest of the capital, West Shewa in Oromia and next to the capital, and in Arsi also in Oromia.

In sum, we find that the technical transformation of cereal production in Ethiopia promoted by the government in recent years has been partial and incomplete. First, the technology package combining the use of improved seed varieties and chemical fertilizers has not been adopted as promoted, and the observed adoption refers in most cases to the use of chemical fertilizer, with significant adoption of improved seeds only observable in maize production. Second, although we verify that the area under improved technology has been growing, the share of cereals produced using the new technology is still low, with decreasing or even negative rates of adoption in recent years. Finally, we find that the adoption of new technology follows a clear spatial pattern, occurring mainly in areas linked to main roads and cities and with suitable natural resources. In the next section we go beyond the description of the adoption process, analyzing the main determinants and variables that explain adoption of the new technology.

3. Technology adoption in agriculture: a conceptual framework

3.1. Methodology

In this section, we discuss the factors affecting technology adoption in agricultural production. Numerous econometric models have been applied to study the adoption behavior of farmers and to identify the key determinants of technology adoption. The econometric specification largely depends on the purpose of the study and the type of data available. In many cases, data are collected on whether a given technology has been adopted or not, without additional information on the constraints some producers might face in accessing the technology. One of the most used methods for modeling technology adoption behavior is the censored regression model, also called the Tobit model. The key underlying assumption for a Tobit specification is that farmers demanding modern inputs have unconstrained access to the technology. However, in situations where input supply systems are underdeveloped this is often untenable, as farmers wanting to apply fertilizer or improved seeds often face input access constraints. The Tobit specification has no mechanism to distinguish households with a constrained positive demand for the new technology from those with unconstrained positive demand, and assumes that a household not adopting the technology is making a rational decision. Hence, for access constraints to inputs, the Tobit model yields inconsistent parameter estimates (Croppenstedt, Demeke, and Meschi 2003).

Evidence from previous studies shows the critical role that underdeveloped input supply and marketing systems play on input choices and technology adoption in smallholder agriculture (Shiferaw, Kebede, and You 2008). However, information and local availability of inputs and farmers' ability to access those inputs are critical in facilitating the process of technology adoption. Smallholder farmers in many rural areas are semisubsistence producers and consumers who are partially integrated into imperfect rural markets. Factor markets for labor, land, traction power, and credit in rural areas of developing countries are often imperfect or even missing in some cases (Holden, Shiferaw, and Pender 2001; Pender and Kerr 1998). In these cases, access to fertilizer and improved seeds is the key threshold that farmers with positive desired demand for the new technology have to overcome. Assuming that many Ethiopian households face constraints in accessing inputs like fertilizer and improved seed varieties, the double-hurdle (DH) model (Cragg 1971) is a useful and proper approach to analyze technology adoption under constrained access to inputs. The DH model examines technology adoption in two stages. In the first stage, the farmer decides whether or not to participate in the fertilizer (or improved seed) market. If he/she chooses to participate, the next step is to decide the quantity to purchase. In this model, the zero values in the dependent variable representing nonadoption of the technology could result either from households that decided not to adopt the technology or households that have the willingness to adopt but are not able to do so due to reasons not embodied in the Tobit framework (for example, the nonavailability of inputs discussed above). In other words, the DH model allows us to separate the sample of farming households into three groups: households applying fertilizer (or improved seed), households wanting to adopt but reporting no positive application, and households choosing not to adopt. Using the DH model to incorporate this additional information allows us to obtain more efficient and consistent estimates of technology adoption by examining a corner solution problem.

The DH model used in this study has two equations, one explaining access to fertilizer or improved seed, and the other one explaining the level of fertilizer or improved seed applied once access to inputs is granted. First, the latent but unobservable variable underlying an individual farmer's access to fertilizer or improved seed A^*can be modeled as:

$$A^* = x_1\gamma + e, \qquad (1)$$

where x_1 is a vector of variables that affect access, γ is the parameter vector, and e is random variable distributed as normal with mean 0 and variance 1. The unobserved desired demand for fertilizer or improved seed for farmers (Y^*) can be modeled as:

$$\mathrm{Y}^* = x_2\beta + \mathrm{u}, \tag{2}$$

where x_2 is a vector of variables that determine the demand function, β is parameter vector, and u is normal random variable with mean 0 and variance σ_u^2.

The observed input demand (Y) is characterized by the interaction of equations (1) and (2). A positive use of input is observed if two thresholds are passed in the decisionmaking process: The farmer has passed the positive demand threshold (Y^* > 0) and has access to input (A^* > 0), which represents the first group in the sample. The second group in the sample includes farmers who want input (Y^* > 0) but cannot get it because of some constraints like lack of access (A^* ≤ 0). The third group in the sample consists of farmers who do not want to use input (Y^* < 0) whether they have access to it or not (A^* > 0 or A^*≤ 0).

We assume that the access and demand equations are independent and that the log-likelihood function for the sample-separated data can be expressed as:

$$\ln\mathrm{L} = \sum_{\mathrm{G1}=1} \ln[\Phi(x_1\gamma) \times (\frac{1}{\sigma_\mathrm{u}}) \times \phi(\frac{\mathrm{Y} - x_2\beta}{\sigma_\mathrm{u}})]$$

$$+ \textstyle\sum_{\mathrm{G2}=1} \ln[\Phi(x_2\beta/\sigma_\mathrm{u}) \times (1 - \phi(x_1\gamma)] + \sum_{\mathrm{G3}=1} \ln[1 - \Phi(x_2\beta/\sigma_\mathrm{u}) \quad (3)$$

where φ and Φ are the probability density and cumulative distribution function of the standard normal variable, respectively; G1, G2, and G3 are indicator functions showing whether a given observation belongs to group one, two, or three, respectively, as described earlier. Equation (3) can be estimated using maximum likelihood (ML) techniques, which give consistent estimates of the parameters. If $\mathrm{u_i}$ and $\mathrm{e_i}$ are independent, the ML function can be separated into a probit and a truncated normal regression model. The model specification of the DH estimator can be tested against the Tobit model using a likelihood ratio (LR) test to determine whether the data support sequential technology adoption decisions or traditional probit and Tobit approaches are sufficient.

3.2. Endogeneity and average partial effects

Parameter estimates could be inconsistent if the independent variables are correlated with unobservable factors affecting adoption behavior. We address the potential endogeneity problem by using the control function (CF) approach (Rivers and Vuong 1988). In the standard case where endogenous explanatory variables are linear in parameters, the CF approach leads to the usual two stage least square (2SLS) estimator. But there are differences for models nonlinear in endogenous variables even if they are linear in parameters. The CF approach offers some distinct advantages for models that are nonlinear in parameters because the CF estimator tackles the endogeneity by adding an additional variable to the regression, generating more precise and efficient estimator than the instrumental variable (IV) estimator (Wooldridge 2008).

The CF approach provides a straightforward two-step procedure to test and control for endogeneity of explanatory variables in modern technology access and demand (Wooldridge 2008). Let $\mathrm{y_1}$ denote the response variable (including Y^* and A^* in equations [1] and [2], respectively), $\mathrm{y_2}$ the endogenous explanatory variable (a scalar), and z the vector of exogenous variables including X and M in equations (1) and (2) with unity as its first element. Consider the model:

$$y_1 = z_1\delta_1 + a_1y_2 + u_1, \quad (4)$$

where z_1 is a strict subvector of z that also includes a constant, and δ_1 and a_1 are parameters to be estimated. The exogeneity of z is given by the orthogonality (zero covariance) conditions

$$E(z'u_1) = 0. \quad (5)$$

The first step in the CF approach is to estimate a reduced form equation of endogenous explanatory variable. Just as in 2SLS, the reduced form of y_2—that is, the linear projection of y_2 onto the exogenous variables—plays a critical role, and adding an error term is expressed as:

$$y_2 = z\pi_2 + v_2, \text{ with} E(z'v_2) = 0, \quad (6)$$

where π_2 are parameters to be estimated. Endogeneity of y_2 arises if and only if u_1 is correlated with v_2. Write the linear projection of u_1 on v_2 in error form, as:

$$u_1 = \rho_1v_2 + e_1, \quad (7)$$

where $\rho_1 = E(v_2u_1)/E(v_2^2)$ is the population regression coefficient. By definition, $E(v_2e_1) = 0$ and $E(z'e_1) = 0$ because u_1 and v_2 are both uncorrelated with z.

In the second step, the residuals obtained from the reduced form are used as an additional explanatory variable in the structural model regression of the DH model. Plugging u_1 in equation (7) into equation (4) gives:

$$y_1 = z_1\delta_1 + a_1y_2 + \rho_1v_2 + e_1, \quad (8)$$

where v_2 appears as an explanatory variable in the equation. As just noted, e_1 is uncorrelated with v_2 and z. Plus, y_2 is a linear function of z and v_2, and so e_1 is also uncorrelated with y_2. This suggests that an ordinary least square (OLS) regression of y_1 on z_1, y_2, and v_2 provides consistent estimates of δ_1 and a_1 (as well as ρ_1), because OLS consistently estimates the parameters in any equation where the error term is uncorrelated with the right-hand side variables. However, v_2 is not observable. We can rewrite $v_2 = y_2 - z\pi_2$ and consistently estimate π_2 by OLS and replace v_2 with $\hat{v}_2$, the OLS residuals from the first-stage regression of y_2 on z. Simple substitution gives:

$$y_1 = z_1\delta_1 + a_1y_2 + \rho_1\hat{v}_2 + \text{error}, \quad (9)$$

where $\text{error}_i = e_{i1} + \rho_1z_i(\hat{\pi}_2 - \pi_2)$ for each observation i, which depends on the sampling error in $\hat{\pi}_2$ unless $\rho_1 = 0$.

The OLS estimates from equation (9) are control function estimates, because of the inclusion of the residuals $\hat{v}_2$ controls for the endogeneity of y_2 in the original equation (although it does so with sampling error because $\hat{\pi}_2 \neq \pi_2$). The OLS estimators are consistent for δ_1, a_1, and ρ_1, and they are identical to the 2SLS estimates of equation (9) using z as the vector of instruments. We can test for the existence of endogeneity $H0$: $\rho_1 = 0$, as the usual t statistic is asymptotically valid under homoscedasticity—$\text{Var}(u_1|z, y_2) = \sigma_1^2$

under H0; or use the heteroscedasticity-robust version (which does not account for the first-stage estimation of π_2).

In cases where the endogenous explanatory variable is discrete, as with binary variables, the CF approach involves estimating

$$E(y_1|z, y_2) = z_1\delta_2 + a_1 y_2 + E(u_1|z, y_2). \qquad (10)$$

Assuming $y_2 = 1$ if $z\delta_2 + e_2 > 0$, (u_1, e_2) is independent of z, $E(u_1|e_2) = \rho_1 e_2$, and e_2 ~Normal(0,1), then

$$E(u_1|z, y_2) = E[E(u_1|z, e_2)|z, y_2] = \rho_1 E(v_2|z, y_2) \qquad (11)$$

$$= \rho_1[y_2\lambda(z\delta_2) - (1 - y_2)\lambda(-z\delta_2)],$$

where $\lambda = \phi(\cdot)/\Phi(\cdot)$ is the inverse Mills ratio. A simple two-step estimator is to first obtain the probit estimator $\hat{\delta}_2$ and then to add the generalized residual,

$$\widehat{gr}_{i2} = y_{i2}\lambda(z_i\hat{\delta}_2) - (1 - y_2)\lambda(-z\hat{\delta}_2), \qquad (12)$$

to the regression of $y_1 = z_1\delta_1 + a_1 y_2 + \tau\widehat{gr}_2$ in the second step.

If the coefficient on the generalized residual is significantly different from zero in the structural model, the explanatory variable of interest, y_2, is endogenous in a farmer's decision to adopt modern technology. Using the reduced form residual can control for endogeneity of y_2 and hence produces consistent estimates in the adoption equation.

After obtaining coefficient estimates for parameters of interest, we derive the average partial effects (APEs) of the explanatory variable across plot and time. The APE is the partial effect averaged across the sample. The first step in obtaining the APE is to derive the partial effect for the explanatory variable of interest x_j for each observation in the sample. The partial effect of a variable $x_j$on the unconditional expected value of y depends on whether x_j is an element of access equation (2) or demand equation (1) or both (Burke 2009). First, if x_j is an element of both equations, the partial effect is:

$$\frac{dE(y)}{dx_j} = \gamma_j * f(x_1\hat{\gamma}) * [x_2\hat{\beta} + \sigma \times \lambda\left(\frac{x_2\beta}{\sigma}\right)] \qquad (13)$$

$$+\beta_j F(x_1\hat{\gamma}) \times \{1 - \lambda\left(\frac{x_2\beta}{\sigma}\right)[\left(\frac{x_2\beta}{\sigma} + \lambda\left(\frac{x_2\beta}{\sigma}\right)\right)]\}.$$

If x_j is only determining the probability of y > 0 in the access equation (1), then β_j = 0 and the second term on the right-hand side of equation (13) disappears. If x_j is only determining the value of y in the demand equation (2), given that y > 0, then γ_j = 0 and the first term on the right-hand side is canceled.

The APE for a continuous variable of our DH model is then calculated as the average of the partial effects. The APE of a binary explanatory variable is calculated as the mean difference between unconditional expected value, $E(y)$, valued at the binary variable D = 0 and D = 1. The APE is generally of greater interest than the partial effect at the average of the sample mean, particularly in nonlinear models and with discrete variables (Wooldridge 2008). However, the APE obtained from the control function approach outlined above cannot be used for statistical inference. Therefore, the bootstrap method is used to obtain the variances of APE and their associated significance levels.

4. Empirical results

4.1. Econometric analysis

Following the discussion above and the conceptual framework in Section 3, we classified variables affecting the ability to access fertilizer or improved seeds as follows: (a) financial constraints—access to credit; (b) fixed costs of adopting the technology; and (c) spatial constraints and supply-side effects. Similarly, we group variables affecting the demand of fertilizer in (a) variables affecting productivity in the use of fertilizer; (b) resource availability and risk-related variables; and (c) spatial variables affecting prices and profitability. Table 4.1 summarizes the variables used in the analysis.

Table 4.1. Factors used to determine fertilizer adoption

Type	Variable	Plot	Holder	Household	*Woreda*
Access to fertilizer					
Financial constraints	Access to credit		X		
Fixed costs of adoption	Access to extension	X			
	Access to advisory service		X		
	Gender		X		
	Age		X		
	Education grade		X		
	Area share of crop land using fertilizer			X	X
Spatial constraints, supply-side effects	Market access				X
	Population density				X
	Road density				X
	Zonal dummies				
	Year dummies	X			
Use of fertilizer					
Variables affecting productivity in the use of fertilizer	Irrigation	X			
	Use of pesticide and herbicide	X			
	Monocrop in the particular plot	X			
	Crop rotation		X		
	Access to extension	X			
	Access to advisory service		X		
	Gender		X		
	Age		X		
	Education grade		X		
	Area share of crop land using fertilizer			X	X
	Area share of highly suitable land				X
	Area share of moderately to marginally				X
Resource availability and risk-related variables	Household size			X	
	Total cereal area			X	
	Area share of the crop in total cereal area			X	
	Number of plots		X		
	Access to land (plot is rented)	X			
Spatial constraints, supply-side effects	Market access				X
	Population density				X
	Road density				X
	Zonal dummies				X
	Year dummies	X			

Source: Variables from CSA Agricultural Sample Survey data (various years).

As suggested by Just and Zilberman (1983), fixed costs incurred when adopting the new technology are important in determining the possibility of adoption. These fixed costs result from the farmer's need to access knowledge that would allow him/her to implement the new technology effectively. In our model, the importance of these knowledge-related costs depends on farmers' access to extension services; farmers' characteristics like gender, age, and education; and the level of adoption in the district where the farmer is located (measured as the share of the crop using improved technology in total area of that crop in the district). We expect a positive relationship between access to fertilizer (and improved seed) and access to extension services, education, and the level of adoption at the district level. Supply-side effects such as lack of supply, late delivery, and inadequate infrastructure are captured by variables representing market access, population, and road density and zonal dummies (Croppenstedt, Demeke, and Meschi 2003).

The first group of variables explaining demand of fertilizer includes those variables that affect productivity in the use of fertilizer. Within this group, irrigation and the use of pesticide and herbicide are considered complementary technologies that can increase productivity of fertilizer. Farmers' characteristics like gender, age, and education can also affect productivity of fertilizer use. Quality of natural resources measured as suitable area in the district where the farmer is located is used as an indicator of expected response of fertilizer. Finally, specialization in a particular crop can improve the efficiency in the use of fertilizer in that particular crop.

Resource availability and risk-related variables are also key determinants in the adoption decision and intensity of fertilizer use. A wealthier farmer exhibits decreasing absolute risk aversion but increasing relative risk aversion, meaning that the farmer will tend to use higher absolute levels of inputs but less inputs per hectare than less wealthier producers (Coady 1995). We expect variables indicating wealth and capital availability as total area and access to additional land (renting land) to be positively related to fertilizer use, with estimated coefficients smaller than 1 if households are relatively risk averse. The share of the crop in total area reflects the importance of the crop in the production system, and we expect this variable to be positively related to fertilizer use. The correlation between household size and fertilizer use should be positive for two reasons. First, we assume that fertilizer application is a labor-intensive task, and with the cost of family labor being lower than that of hired labor, a positive coefficient for this variable captures this lower cost of applying fertilizer (Coady 1995). A second explanation for a positive coefficient of household size is related to risk. With labor being a safe asset, compared to crop production, more family labor is equivalent to a higher level of nonstochastic assets, allowing for higher use of fertilizer.

Spatial variables like market access, population density, and road density affect the level of fertilizer use through marketing and transportation margins affecting the prices that farmers pay for fertilizer and eventually also the price they receive for their products. Zonal dummies represent other specific spatial effects not captured by other variables.

4.1.1. Determinants of fertilizer access

Treating extension as endogenous variable, Table 4.2 reports results of the econometric estimation of the DH model for fertilizer access. Some common patterns emerge across crops in explaining farmers' access to fertilizer. The main explanation of fertilizer access is the possibility of reducing the fixed knowledge cost related to adoption of the new technology, mainly through access to extension services. Also important in explaining access to fertilizer is the share of total cereal land under fertilizer both at the household level and at the district (woreda) level where the household is located. The positive and significant coefficient suggests: (1) fertilizer is more likely to be adopted in households who have already used it in other crops because the use of fertilizer in other crops improves the farmer's skill and makes the household more likely to use fertilizer in the crop of interest; (2) there exists a peer effect among farmers, or learning from the neighbors, and better access to knowledge on the new technology encourages higher level of adoption in the district.

Table 4.2. Double hurdle regression estimates for fertilizer access, extension treated as endogenous

	Maize		Teff		Wheat		Barley	
Fertilizer access	Coefficient	P > z	Coefficient	P > z	Coefficient	P > z	Coefficient	P > z
Credit (yes = 1)	-0.094	0.000	0.027	0.185	0.067	0.002	-0.115	0.000
Extension (yes = 1)	2.646	0.000	0.014	0.902	0.231	0.059	1.611	0.000
Advisory service (yes = 1)	-0.299	0.000	0.012	0.677	0.070	0.083	-0.263	0.000
Gender (male = 1)	0.013	0.527	0.093	0.000	-0.000	0.987	0.067	0.024
Age	-0.002	0.000	0.001	0.306	-0.003	0.000	-0.004	0.000
Education grade	0.004	0.173	-0.003	0.440	0.001	0.828	0.000	0.997
Area share of total crop land using fertilizer (household)	0.022	0.000	0.040	0.000	0.035	0.000	0.031	0.000
Area share of total crop land using fertilizer (*woreda*)	0.010	0.000	0.012	0.000	0.013	0.000	0.013	0.000
Market access (*woreda)*	-0.000	0.000	0.000	0.001	-0.001	0.000	-0.000	0.000
Population density (*woreda*)	0.000	0.048	-0.000	0.037	0.000	0.162	-0.000	0.854
Road density (*woreda*)	-0.001	0.000	-0.001	0.000	-0.001	0.001	-0.001	0.007
Generalized residual	-0.477	0.000	0.497	0.000	0.383	0.000	-0.449	0.000
Constant	-2.652	0.000	-2.450	0.000	-2.322	0.001	-3.827	0.000
Observations	110,162		89,533		60,228		62,026	
Log-likelihood	-167.6		4,820		7,412		3,635	
P-value of Wald test of independent equations (rho = 0)	0.274	0.000	0.290	0.000	0.257	0.000	0.259	0.000
P-value of LR test of Tobit model	19,983	0.000	25,783	0.000	21,405	0.000	12,830	0.000

Source: Author's calculation using CSA data (various years).

Holders' characteristics also affect access to fertilizer. In particular, age has a significant and negative effect on the likelihood of fertilizer adoption for maize, wheat, and barley, supporting the hypothesis that older holders are less likely to access the new technology than younger holders. Accessibility is better in male-headed households than their female-headed counterparts among teff and barley farmers. Unexpectedly, no relation between access to fertilizer and education was found.

The spatial variables included to explain access don't appear to have a major impact in determining fertilizer use as their coefficients are quite small. For maize, the spatial effects are better captured by the zonal dummies (not reported). Access to fertilizer in maize production is more likely in the south and southwest, around Awasa and Jimma, in West Oromia, and in the zones crossed by the major road going east to Djibouti: West and East Hararge, West Arsi, and Harari). Coefficients of the dummy variables for teff show that some zones are disadvantaged to access fertilizer. Most of these zones are in SNNP and in particular in Amhara, where several zones with high teff production appear to have difficulties accessing the technology. For wheat, none of the coefficients of the zonal dummy variables is significant, indicating that only variables related to fixed costs of the technology are relevant when explaining access to fertilizer.

4.1.2. Determinants of fertilizer demand

Results for the estimation of the model explaining area planted with fertilizer conditional to access to fertilizer are presented in Table 4.3. Area under fertilizer is mainly explained by variables affecting productivity in the use of fertilizer: specialization in the particular crop, captured by monocrop production at the plot level; access to inputs through extension specialists; previous knowledge and experience in cereal represented by crop rotation; access to land rental market and land fragmentation; total cereal area; crop's share in total household cultivated cereal area; and the area under fertilizer in the woreda for maize, wheat, and barley. In particular, wealth and risk together with specialization play a major role in explaining fertilizer use. Households with more land in cereal production and a greater share of the particular crop in the production system are related to higher fertilized area, whereas households that rent land for crop production show larger area under fertilizer than those with no access to land. We assume this variable also reflects wealth and financial possibilities of households. As with total land under cereal production, having access to land rental market results in an absolute increase in the area under fertilizer but a reduced share of this area in total cereal land. Coefficients obtained for land rental in the different crops support the view that households compensate for the additional risk of increasing area of a crop by reducing input intensity for that crop.

Results show that irrigation does not encourage more intensive fertilizer use in maize and barley and is negatively related to fertilizer use in teff and wheat, which suggests that farmers still view irrigation as a substitute for other inputs rather than as a complementary technology. Land fragmentation can be a detriment in fertilizer adoption: Holding everything else constant, a holder planting one more plot decreases the area under fertilizer by 0.04–0.06 hectare.

In contrast with other studies (for example, Croppenstedt, Demeke, and Meschi 2003), family size does not appear to play a significant role determining fertilizer use. As fertilizer is assumed to be a labor-intensive technology, it is expected that availability of family labor would result in higher fertilizer use. Only for wheat do we find that household size is positively and significantly related to area under fertilizer. A possible explanation for our results is that our dependent variable is area under fertilizer and not amount of fertilizer use. If household size does not affect the area but only the intensity of fertilizer used, then our model cannot capture this effect.

Table 4.3. Double hurdle regression estimates for fertilizer use, extension treated as endogenous

	Maize		Teff		Wheat		Barley	
Area under chemical fertilizer	Coefficient	P > z	Coefficient	P > z	Coefficient	P > z	Coefficient	P > z
Irrigation (yes = 1)	-0.049	0.216	-0.208	0.000	-0.136	0.003	-0.044	0.561
Pesticides and herbicides (yes = 1)	0.019	0.547	0.053	0.000	0.055	0.000	0.089	0.000
Monocrop (yes = 1)	0.243	0.000	0.132	0.000	0.514	0.000	0.157	0.000
Crop rotation (yes = 1)	0.039	0.008	0.034	0.004	0.055	0.000	0.006	0.769
Extension (yes = 1)	0.187	0.005	0.102	0.005	0.071	0.097	0.148	0.017
Advisory service (yes = 1)	-0.015	0.505	-0.024	0.037	-0.014	0.363	-0.026	0.237
Gender (male = 1)	0.076	0.000	0.029	0.000	0.020	0.014	0.020	0.182
Age	0.001	0.000	0.003	0.000	0.003	0.000	0.002	0.000
Education grade	-0.007	0.000	0.001	0.114	-0.000	0.813	0.004	0.046
Area share of total crop land using fertilizer	0.000	0.525	0.000	0.045	-0.000	0.135	-0.000	0.142
Area share of total crop land using fertilizer (*woreda*)	0.001	0.043	-0.001	0.000	0.001	0.007	0.002	0.000
Share of highly suitable land	0.025	0.160	0.005	0.785	0.018	0.378	-0.062	0.019
Share of moderately to marginally suitable land	-0.018	0.542	-7.185	0.024	0.573	0.000	-0.098	0.082
Household size	0.000	0.783	-0.001	0.217	0.004	0.002	0.002	0.347
Cereal area	0.317	0.000	0.182	0.000	0.155	0.000	0.281	0.000
Share of the crop in total cereal area	0.006	0.000	0.004	0.000	0.004	0.000	0.007	0.000
Number of plots under holder	-0.047	0.000	-0.044	0.000	-0.038	0.000	-0.057	0.000
Plot is rent (yes = 1)	0.050	0.001	0.000	0.992	0.038	0.000	0.105	0.000
Market access	0.000	0.000	0.000	0.000	0.000	0.411	0.000	0.449
Population density	-0.000	0.000	-0.000	0.017	-0.000	0.001	-0.000	0.160
Road density	0.000	0.478	-0.000	0.000	-0.001	0.000	-0.001	0.000
Generalized residual	-0.041	0.290	-0.054	0.011	-0.020	0.419	-0.076	0.026
Constant	-0.676	0.000	-0.420	0.000	-0.443	0.551	-1.626	0.005

Source: Author's calculation using CSA data (various years).

Among holder characteristics we find that age has a positive and statistically significant effect on fertilizer demand in all crops, suggesting that among adopters, past farming experience is related to efficiency and knowledge in the use of fertilizer. We also find a significant effect of gender in conditioning fertilizer demand, and households with more educated heads exhibit higher fertilizer adoption in barley production but not in maize. Coefficients of crop suitability, population, and road density are insignificant or negative, whereas coefficients of market access are positive for maize and teff. This suggests that fertilizer is blindly applied to the field depending on accessibility, rather than guided by appropriate technology that is modified to local biophysical conditions and infrastructure.

The coefficients for generalized residual from the control function (CF) are significant in the fertilizer access function for all four crops, but only in the demand function of teff and barley, indicating that the extension service is endogenous in the decisionmaking process of fertilizer adoption. Compared to the coefficients obtained under the assumption of exogenous extension, the coefficients using CF are smaller in the access function, but larger in the demand function, meaning extension service boosts the probability of fertilizer access but does not affect fertilizer demand among users. The effect is not negligible, probably because many farmers are using chemical fertilizer, which is mostly distributed through extension services.

The separability of the likelihood function or independence hypothesis is rejected for all cases, suggesting that the two error terms from probit and truncated regressions are correlated (Table 4.2). We maintain the independence assumption because we believe our model is correctly specified and this assumption facilitates estimation. We maintain the independence assumption in this study because we believe our model is correctly specified and the independence assumption facilitates estimation. Studies comparing results from a model under independent error term assumption with results from the same model under relaxed error term assumption have found virtually identical coefficients and standard error (Jones 1992; Garcia and Labeaga 1996) when the model is correctly specified.

We can also test whether farmers make input decisions simultaneously versus sequentially by inspecting how well the Tobit model fits our data when compared with the DH model. By estimating each model separately with the variables presented in Table 4.3 we find that the log-likelihood of the DH model is larger than that of the Tobit model, confirming the relative superiority of the DH specification for this dataset over the Tobit model (Table 4.2). The result indicates that adoption of chemical fertilizer needs to be estimated conditional on the fertilizer access threshold. This provides evidence that farmers in Ethiopia make input market decisions sequentially by first deciding to adopt or not and then deciding how much to apply in the field, leading to an elastic demand for chemical fertilizer.

4.1.3. Determinants of improved seed adoption in maize

The estimated parameters for the DH model on access and demand for improved seed use in maize are shown in Table 4.4. The main explanation of access to improved seed is the possibility of reducing the fixed knowledge cost related to adoption of the new technology. Among the variables related to this fixed cost, the large and positive coefficient of access to extension services highlights the important role that extension services play in the adoption of improved seed. A second major variable explaining access to improved seed is the share of crop land under improved seed in the district where the household is located, which as with fertilizer, suggests a peer effect and better access to knowledge about the new technology. Among holders’ characteristics, education and gender rather than age, as with fertilizer, are the variables with the greatest effect on access to the new technology.

The spatial variables included to explain access don’t appear to have major effects in determining use of improved seed, and, as with fertilizer, the spatial effects are better captured by the zonal dummies. Coefficients of these variables show that access to improved maize seed is more likely for farmers in Oromia, in particular in East Hararge, Guji, West Arsi, Wellega, Shewa, and Illu Ababora, and in SNNP (Hadiya, Amaro, Yem, Gamo Goffa, Basketo, and Wolayita).

Table 4.4. Double hurdle regression estimates for improved seed use in maize, extension treated as endogenous

Improved seed access			Area under improved seed		
	Coefficient	P > z		Coefficient	P > z
Extension (yes = 1)	3.323	0.000	Irrigation (yes = 1)	0.018	0.741
Advisory service (yes = 1)	-0.583	0.000	Pesticide and herbicide (yes = 1)	-0.041	0.378
Share of total crop land using fertilizer (*woreda*)	0.007	0.000	Crop rotation (yes = 1)	0.042	0.029
Area share of crop land using fertilizer (in other crops, household)	0.030	0.000	Extension (yes = 1)	0.353	0.000
Gender (male = 1)	0.093	0.001	Advisory service (yes = 1)	-0.076	0.003
Age	0.001	0.062	Area share of highly suitable land	0.057	0.022
Education grade	0.013	0.000	Area share of moderately to marginally suitable land	-0.083	0.021
Market access	-0.000	0.000	Monocrop (yes = 1)	0.215	0.000
Population density	0.000	0.002	Number of plots under holder	-0.037	0.000
Road density	-0.000	0.693	Share of total crop land using improved seed (*woreda*)	0.282	0.000
Year = 2004	-0.181	0.000	Share of crop land using fertilizer (in other crops, household)	0.003	0.000
Year = 2006	-0.028	0.283	Gender (male = 1)	0.086	0.000
Year = 2007	0.119	0.000	Age	0.001	0.000
Generalized residual	-0.800	0.000	Education grade	-0.007	0.000
Constant	-3.817	0.000	Household size	-0.004	0.060
			Cereal area	-0.001	0.046
			Plot is rented (yes = 1)	0.025	0.136
			Market access	0.000	0.007
			Population density	-0.000	0.000
			Road density	0.003	0.000
			Year = 2004	-0.007	0.584
			Year = 2006	-0.226	0.000
			Year = 2007	-0.186	0.000
Observations	110,162		Generalized residual	-0.162	0.000
Log-likelihood	-3951		Constant	0.000	0.114

Source: Author's calculation using CSA data (various years).

The demand for improved seed conditional on access to the technology is explained mainly by production specialization (monocrop at the plot level) and, unlike fertilizer adoption in Table 4.3, by access to extension and by the total area under crops. Among household characteristics, gender of household head is the most important variable affecting access to seed, whereas the impact of market access is positive but small. The effect of population density is also small but negative. It is interesting to notice that only six zones have significant coefficients explaining use of improved seed, and that all these coefficients are negative. Four of these regions are regions with better access than average compared to other zones. This means that even though the probability of plots using improved seed is higher in these zones than in an average zone, given access, these zones have lower area under improved seed than the average zone.

4.1.4. APE

Table 4.5 provides the average partial effects (APEs), which are useful for our case with nonlinear model and discrete variables. The APES are obtained by bootstrap of 100 iteration to obtain the variances of APE and their associated significance levels. The table shows that extension has a significant positive effect on fertilizer adoption. For example, households having access to an extension technician can increase the average maize area under fertilizer by 0.1 hectare. The higher the share of crop area under fertilizer at household and district level, the higher fertilizer use intensity.

Farmers' skills and knowledge, represented by monocrop, crop rotation, and uses of chemicals, all contribute to the quantity of fertilization use. APEs of variables associated with household wealth confirm that households have exhibited decreasing absolute risk aversion but increasing relative risk aversion. Fragmented land plots prevent wide adoption of technology due to the limited operation scale. On average, a plot managed by a male holder tends to have higher fertilizer use, so does one managed by an older holder.

The results suggest that although infrastructure factors (like market access, population, and road density) do have an impact on fertilizer adoption, their effects are small and not comparable with the agroecological constraints defined by crop suitability. Combined with the negative effect of advisory service and irrigation, it is important to pay attention to the efficiency of the promotion program as farmer's technology adoption behavior appears to be unrelated to local agronomical conditions, especially for teff and barley.

There are several existing studies exploring the issue of technology adoption in Ethiopia. Land size, household head age, and access to information are identified as the major factors affecting technology adoption (Admassie and Ayele 2004). Based on household panel data, Endale (2011) argues that household gender does not affect the decision to use fertilizer, but labor educational level does. Similar to the results of this paper, they also report positive correlation between household size and fertilizer adoption. The results highlight the importance of financial resources of the household in adoption decision, including credit, wealth expressed as livestock, and land size. Our results are consistent with these studies, especially in the role of household resources and access to knowledge.

Table 4.5. Average partial effects of factors on chemical fertilizer adoption

	Maize		Teff		Wheat		Barley	
	APE	t-value	APE	t-value	APE	t-value	APE	t-value
Variables in both demand and access equations								
Extension	0.1007	7.9	0.0209	2.6	0.0184	2.2	0.0342	5.4
Advisory service	-0.0056	-4.0	-0.0043	-2.0	-0.0012	-0.4	-0.0046	-3.7
Gender	0.0040	5.5	0.0072	4.7	0.0034	0.9	0.0017	1.9
Age	0.0000	0.9	0.0005	8.4	0.0004	6.9	0.0001	3.3
Education grade	-0.0003	-3.2	0.0002	0.9	-0.0001	-0.2	0.0002	1.6
Area share of total crop land using fertilizer (household)	0.0004	22.6	0.0010	36.4	0.0007	22.5	0.0004	22.1
Area share of total crop land using fertilizer (*woreda*)	0.0002	11.8	0.0001	4.9	0.0003	10.7	0.0003	16.4
Market access	0.0000	1.1	0.0000	10.8	0.0000	-1.1	0.0000	-1.2
Population density	0.0000	-2.2	0.0000	-3.0	0.0000	-0.4	0.0000	-1.0
Road density	0.0000	-0.7	-0.0001	-5.6	-0.0002	-3.8	-0.0001	-5.7
Variables in demand equation only								
Irrigation	-0.0024	-1.1	-0.0319	-5.9	-0.0212	-3.4	-0.0019	-0.6
Pesticides and herbicides	0.0010	0.5	0.0099	6.1	0.0092	5.8	0.0043	5.3
Monocrop	0.0135	12.6	0.0243	3.5	0.0928	9.7	0.0074	4.0
Crop rotation	0.0020	1.8	0.0060	2.2	0.0085	2.4	0.0003	0.3
Share of highly suitable land	0.0013	1.3	0.0009	0.3	0.0035	0.9	-0.0028	-2.1
Share of moderately to marginally suitable land	-0.0009	-0.5	-1.3125	-2.5	0.0876	4.4	-0.0045	-1.6
Household size	0.0000	0.2	-0.0002	-1.1	0.0006	1.5	0.0001	0.8
Cereal area of household	0.0166	18.4	0.0332	33.5	0.0267	30.8	0.0129	24.1
Share of the crop in total cereal area	0.0003	29.7	0.0008	34.5	0.0008	31.8	0.0003	28.1
Number of plots under holder	-0.0025	-16.7	-0.0081	-18.7	-0.0065	-25.1	-0.0026	-19.4
Plot is rent	0.0027	3.1	0.0000	0.0	0.0067	4.6	0.0052	6.1

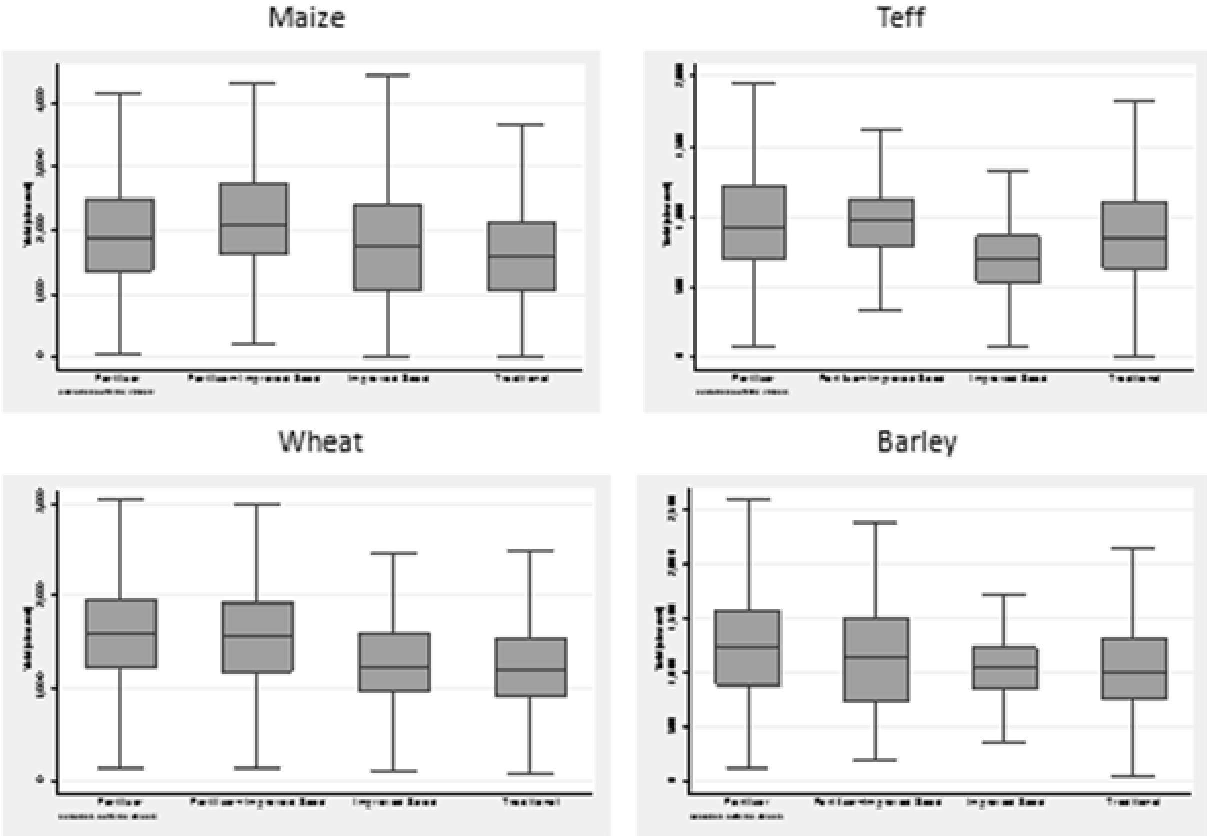
Source: Author’s calculation using CSA data (various years).

5. Further discussion

Our econometric results show that access to the new technology is affected mainly by fixed costs of knowledge related to an effective use of the technology. Results show that Ethiopia's extension service played an important role in facilitating farmers' access to modern technology by promoting technology packages tied to credit. However, several shortcomings of the government-controlled system determined that the final result of this effort was below the expected goals. Among the major problems identified were the poor performance of the seed system, the limited availability of high-quality improved seed, and the inefficiency of fertilizer use, which can be related to the rigidity of the package promoted and the nonavailability of fertilizer formulas adapted to different agroecological needs, the priority of the extension system to distribute inputs rather than provide technical advice, and the limited role of the private sector in the system. All these problems resulted in low efficiency in the use of fertilizer at the farm level, affecting adoption of improved seed and efficiency in the use of fertilizer and seed.

Figure 5.1 shows the limited impact of the new technologies on yields of maize, teff, wheat, and barley. First, the median of the yield distribution obtained using fertilizer plus seed in maize and wheat is larger than that of the traditional technology but far from the expectations that the authorities had of doubling yields when the program was launched. Second, the difference between the median of the distribution of yields obtained by using fertilizer only and those obtained by using fertilizer plus seed are small for maize and almost zero for wheat. This means that given the actual efficiency in the use of the fertilizer plus seed technology, the low use of improved seed could be explained, together with the lack of seed availability, by the low efficiency in the use of seed that results from inadequate practices and low quality of seed. Third, the highest yields (those in the 90th percentile of the distribution) are close to those obtained in trials and experiments during the first phase of PADETES: 3,700 kilograms per hectare in maize and close to 3,000 kilograms per hectare in wheat. Reducing the high variability observed in yields with seed plus fertilizer technology should result in movements of the mean and median of the yield distribution closer to what today are frontier values (high yield), resulting in improved conditions and incentives to adopt the technology. Fourth, median yields obtained in teff and barley using the seed plus fertilizer technology are low and similar to those obtained using the traditional technology, with frontier values in the improved technology being much lower than those obtained with the traditional technology. This suggests that availability of improved varieties in teff and barley is still a major constraint to increasing yields and that the only technical alternative to the traditional technology is the use of chemical fertilizer. The possibilities of increasing yields of these crops using fertilizer only are quite limited as can be observed in the figure. Finally, the distribution of maize and wheat yields obtained using improved seed and fertilizer are also indicative of the problems that a risk-averse producer faces when deciding to adopt the new technology, and this is not even considering price risk, which corresponds with our results showing that smallholders tend to have less areas under fertilizer.

Figure 5.1. Yield distributions of cereals at the plot level different input combinations (average values 2003–07 in kilograms per hectare)



Source: Authors' calculation using CSA Agricultural Sample Survey data (various years).

6. Conclusion

The impacts of the strategy followed by Ethiopia in recent years to raise cereal production and yields have been mixed, with increased use of fertilizer but without clear results in terms of productivity growth. In this paper we use nationally representative data from the Central Statistical Agency to examine the extent of the adoption of the promoted fertilizer-seed technology package and to identify some of the main factors affecting the use of modern inputs.

We find that variables affecting fixed costs related to the adoption of the new technology, like access to extension service, the level of adoption at the district level, and the experience of farmers using fertilizer in other crops, have a significant effect on the probability of accessing fertilizer and improved seed by farmers. Specialization, together with wealth and risk aversion, also plays a major role in explaining crop area under fertilizer, which should be related to better access to technology-related knowledge. Wealthier households, which are assumed to be those with more land in crop production, tend to have larger areas of land under fertilizer. The estimated coefficients also show that farmers in Ethiopia have increasing relative risk aversion, meaning that households compensate for the additional risk of increasing area of a crop under improved technology by reducing input intensity for that crop. On the other hand, spatial variables included to explain access generally appear to have little effects in determining fertilizer use, despite that access to fertilizer is more likely to encourage fertilizer use in certain zones for maize and teff.

As for fertilizer adoption, several factors affect access to improved seed. The main explanation is the fixed knowledge cost related to adoption of the new technology. Variables affecting this cost are access to extension services and the share of crop land under improved seed in the district where the household is located. Demand for improved seed conditional on access to the technology is explained mainly by production specialization (monocrop at the plot level) and, unlike fertilizer use, by access to extension and by the total area under crops. Among household characteristics, gender is the most important variable affecting access to seed.

The policy implications derived from the results are in line with those in previous studies. First, in order to improve efficiency in the use of inputs, changes are needed in the seed and fertilizer systems and in the priorities of the extension service. These changes include a clear need to increase the participation of the private sector in the seed and fertilizer systems at different levels and to redefine priorities and goals of the extension service developing technical expertise and advice at the local level to adjust technical and economic recommendations to local needs. Second, the results show that farmers are risk averse and that wealthier farmers tend to use more fertilizer than smaller farmers although the intensity in the use of fertilizer declines with wealth (relative risk aversion). Proper policies need to be developed to accommodate risks associated with agricultural production, especially among small and poor households. Given the constraints the country faces to expand the quality and reach of the extension service, credit availability, and the production and distribution of improved seed, clear gains can be made by focusing policy and investment efforts first on maize and wheat production, for which technology is available. Increased availability of improved seed together with increased access to extension services among maize producers could result in increased fertilizer adoption and significantly higher maize yields. Finally, technical constraints appear to be more at the research level for all crops, especially teff and barley. Currently improved seeds of teff and barley appear not available or, at least, the available varieties don’t offer strong benefits compared to traditional varieties. Policy priorities for these crops should focus on research and development investment to generate a diverse range of varieties adapted to local agroecological conditions in Ethiopia.

References

Admassie, A., and G. Ayele. 2004. *Adoption of Improved Technology in Ethiopia.* Working Paper. Addis Ababa: Ethiopia Development Research Institute.

Burke, W. J. 2009. "Fitting and Interpreting Cragg's Tobit Alternative Using Stata." *Stata Journal* 9 (4): 584–592.

Byerlee, D., D. J. Spielman, D. Alemu, and M. Gautam. 2007. *Policies to Promote Cereal Intensification in Ethiopia: A Review of Evidence and Experience.* IFPRI Discussion Paper 00707. Washington, D C: International Food Policy Research Institute.

Coady, D. P. 1995. "An Empirical Analysis of Fertilizer Use in Pakistan." *Economica* 62:213–234.

Cragg, J. G. 1971. "Some Statistical Models for Limited Dependent Variables with Applications to the Demand for Durable Goods." *Econometrica* 39:829–844.

Croppenstedt, A., M. Demeke, and M. Meschi. 2003. "Technology Adoption in the Presence of Constraints: The Case of Fertilizer Demand in Ethiopia." *Review of Development Economics* 7 (1): 58–70.

CSA (Central Statistical Agency). 2009. Annual Agricultural Sample Survey (database). www.csa.gov.et/Annual%20Agricultural%20Sample%20Survey%20and%20Enumeration.htm.

Diao, X., and A. Nin Pratt. 2005. *Growth Options and Poverty Reduction in Ethiopia: A Spatial, Economy-Wide Model Analysis for 2004–15*. With the assistance of M. Gautam, J. Keough, J. Chamberlin, L. You, D. Puetz, D. Resnick, and B. Yu. IFPRI DSGD Discussion Paper 20. Washington, DC: International Food Policy Research Institute.

Endale, K. 2011. *Fertilizer Consumption and Agricultural Productivity in Ethiopia.* EDRI Working Paper 003. Addis Ababa: Ethiopia Development Research Institute.

Garcia, J., and J. M. Labeaga. 1996. "Alternative Approaches to Modeling Zero Expenditure: An Application to Spanish Demand for Tobacco." *Oxford Bulleting of Economics and Statistics* 58 (3): 489–504.

Holden, S. T., B. Shiferaw, and J. Pender. 2001. "Market Imperfections and Land Productivity in the Ethiopian Highland." *Journal of Agricultural Economics* 52 (3): 53–70.

Howard, J., E. Crawford, V. Kelly, M. Demeke, and J. J. Jeje. 2003. "Promoting High-Input Maize Technologies in Africa: The Sasakawa-Global 2000 Experience in Ethiopia and Mozambique." *Food Policy* 28:335–348.

Jones, A. M. 1992. "A Note on Computation of the Double-Hurdle Model with Dependence with an Application to Tobacco Expenditure." *Bulletin of Economic Research* 44 (1): 67–74.

Just, R. E., and D. Zilberman. 1983. "Stochastic Structure, Farm Size, and Technology Adoption in Developing Agriculture." *Oxford Economic Papers* 35 (2): 307–328.

Pender, J., and J. M. Kerr. 1998. "Determinants of Farmers' Indigenous Soil and Water Conservation Investments in Semi-Arid India." *Agricultural Economics* 19:113–125.

Rivers, D., and Q. H. Vuong. 1988. "Limited Information Estimators and Exogeneity Tests for Simultaneous Probit Models." *Journal of Econometrics* 39:347–366.

Seyoum Taffesse, A. 2009. "Cereal Production in Ethiopia: Recent Trends and Sources of Growth." Mimeo. Addis Ababa, Ethiopia: International Food Policy Research Institute.

Shiferaw, B. A., T. A. Kebede, and L. You. 2008. “Technology Adoption under Seed Access Constraints and the Economic Impacts of Improved Pigeonpea Varieties in Tanzania.” *Agricultural Economics* 39:309–323.

Tadesse, M., B. Alemu, G. Bekele, T. Tebikew, J. Chamberlin, and T. Benson. 2006. *Atlas of the Ethiopian Rural Economy.* Addis Ababa: Ethiopian Development Research Institute.

Wooldridge, J. M. 2008. “Control Function and Related Methods.” Unpublished Lecture Notes.

World Bank. 2006. *Ethiopia: Policies for Pro-Poor Agricultural Growth*. Washington, DC: World Bank.