THE STATE OF SUBSISTENCE AGRICULTURE IN ETHIOPIA: SOURCES OF OUTPUT GROWTH AND AGRICULTURAL INEFFICIENCY

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This dissertation is dedicated to three groups of people:

- To my extended family residing in Addis Ababa and Harar.
- To my friends in Addis Ababa, Nazareth, and the Twin cities.
- To the subject of the study: subsistent farmers in Ethiopia.

Abstract

Agriculture dominates the Ethiopian economy, accounting for about 50 percent of its GDP and 82 percent of its employment. However, the sector has always performed poorly; about one-half of the rural residents in Ethiopia live below the national poverty line, and the rural population is endowed with few and poorly provided social amenities. Sectoral-level data shows that the farmers in Ethiopia use little modern inputs and output per hectare is low. With rural population increasing at a fast pace, land holdings have been increasingly fragmented. Although fertilizer is the most widely used modern input, application rates are abysmally low, even by Sub-Sahara Africa standards. Use of improved seeds and pesticides is almost nonexistent.

Among a group of other comparable countries (Sub-Saharan Africa, developing, the poorest five, and Ethiopia's neighboring countries) the Ethiopian agriculture performed the poorest. If Ethiopian farmers were to achieve the average yield levels reported in these comparable countries it would at least be self-sufficient in cereals production; other scenarios show output could grow substantially. Descriptive and comparative analysis conducted on the agroecologic zones included in 5 out of 6 Ethiopian Rural Household Surveys (ERHS) conducted between 1994 and 2004 shows that crop yields increased marginally while the area under cultivation expanded more rapidly. Moreover different zones tended to specialize in one or two crops. Household data indicates that subsistence farmers suffer from shortage of credit, have little exposure to modern production know-how, and most importantly suffer from shortage of rainfall that frequently turns to drought. In a country with ample water resources and where a large majority the population is engaged in rain-fed agriculture, which has become increasingly risky due to persistent drought, will be key to improving the lives of most Ethiopians.

In addition to a descriptive and comparative analysis, this study used panel data from ERHS to statistically analyze the sources of output growth and technical efficiency in subsistence agriculture in Ethiopia. Assessing the sources of increased production, and examining the extent and sources of measured production inefficiencies can reveal options for ameliorating the bleak conditions confronting Ethiopian agriculture. A stochastic frontier analysis (SFA) was used to assess the variation in technical efficiency in addition to accounting for the sources of growth in agricultural output.

There are indications that most of the increase in output in such subsistence agriculture was attained by increased use of traditional inputs, notably the amount of rainfall, the area and quality of cultivated land, and the numbers of oxen and hoes. By contrast, the rate of fertilizer application contributed the least for increase in output. However, participation in a nationally conceived extension program contributed significantly to output gains. Each agro-ecological zone included in the study gained from Hicks-neutral technological improvements during the study period. The average level of farming efficiency for the surveyed farmers across all the years was 0.4, indicating that most of the farmers were less than one-half as efficient as those producing on the frontier. Farm households' level of farming efficiency is improved by reducing labor bottlenecks and increased education. Households that have diversified risk from plots that are located sufficiently apart appear more efficient.

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I. INTRODUCTION

1.1 The Ethiopian Economy- A Comparative Look[1]

In poor countries, agriculture is the largest source of employment and accounts for the largest share of gross domestic product (GDP). On average, 80 percent of the population in the world's five poorest countries of Malawi, Burundi, Congo Democratic Republic, Tanzania, and Niger lived in rural areas in 2005. In these countries, agriculture accounted for 43 percent of GDP in 2003, the most recent year with complete data for all five countries. This number compares with an average agricultural share of just 2.7 percent in the five richest countries of Luxemburg, United States, Norway, Ireland, and Iceland.[2] In the poor economies, agriculture is also characterized by comparatively low productivity per worker and limited use of modern inputs, such as fertilizer or modern seed varieties. Between 2002 and 2005 fertilizer application rates by the five richest countries averaged 773 kilograms per hectare, 100 times more than that used in the five poor countries cited above, which averaged less than 8 kilograms per hectare. From 2000 to 2003, average value added per agricultural worker in four of the five richest counties was $35,885 (2000 prices).[3] This was 220 times more than the corresponding measure for the five poorest countries, which averaged just $163 (2000 prices).

In 2005, Ethiopia was the twelfth poorest country among a total of 208 countries and territories in the world, with GDP per capita of $580 (2005 international dollars); 80 times less than the average for the richest five countries, and about one-half of the corresponding per capita income average for Sub-Saharan Africa. Between 1990 and 2005, Ethiopia's per capita GDP - which averaged $491 (2005 international dollars), grew by 1.5 percent per year, about half the corresponding rate of low-income countries as a group. Average annual household consumption expenditure per capita fluctuated around a 1990 to 2005 average of just $95 per household, ranging from a low of $78 in

[1] The data in this section are from WDI (2007), unless stated otherwise.
[2] The groups are formed by taking the countries with the lowest and highest GDP per capita, correcting for purchasing power parity (PPP), at constant 2000 international dollars in 2005.
[3] Data is missing for Ireland.

1992 to a high of $115 in 2004 (constant 2000 U.S. dollars). A sharp decline in real GDP following the 1991/92 and 1997/98 droughts caused the relatively sharp swings in household consumption expenditure (Easterly 2004). In 2000, an estimated 78 percent of Ethiopians get by with less than two dollars per day and 23 percent get by with less than one dollar per day while the country's national poverty head count index was 44 percent. An Ethiopian born in 2004 had a life expectancy of just 42 years.

The low per capita income in poor countries is exacerbated by comparatively low levels of labor productivity and rapidly growing populations. Rapid population growth is problematic when it increases the number of dependents per worker and when increases in the labor force are not matched by corresponding increases in the means of production, including arable land and physical and human capital. The Population Reference Bureau (2008) estimates that Ethiopia's population of 77 million in 2007 will increase to 109 by 2025 and to 146 million by 2050. This is an increase in population of 90 percent between 2007 and 2050 or an average growth rate of over 2 percent per year. The Population Reference Bureau (2004) cites a high fertility rate combined with a large proportion of young population as an explanation for the tremendous projected increase in population of some countries, including Ethiopia. With fertility rates exceeding 5 children per woman, Ethiopia's crude birth and death rates are far greater than the comparable rates throughout Sub-Saharan Africa and among the group of low-income countries. Add to that the fact that 43 percent of the Ethiopian population is below 15 years of age and 97 percent is below 64 the elements for relatively rapid rates of population growth in the decades ahead are already in place.

As in most poor countries, agriculture is the single most important sector in Ethiopia. In 2005, 84 percent of Ethiopians lived in rural areas while FAO (2005) reports that in 2002, 82 percent of the economically active population worked in agriculture.[4] In 2005, agriculture accounted for 48 percent of the value added to GDP, and about 84 percent to the value of exports, which in total represented 16 percent of GDP. However, the

[4]WDI data for employment in agriculture is missing for almost all years, while this section of FAO's website has not been updated for almost two years.

agricultural sector has always performed poorly on most economic indicators. At just $154 (2000 prices), agricultural value added per agricultural worker in 2004 was less than 0.4 percent of the average for the five richest countries in the world, which was $40,280 per worker. Agricultural value added per agricultural worker in 2003 in Ethiopia was less than one half of the average for Sub-Saharan Africa.

About 45 percent of the residents in rural Ethiopia live below the national poverty line. While 87 percent of urban and 52 percent of rural residents in the poorest five countries in the world had access to improved water sources, only 81 percent of urban and 11 percent of rural residents in Ethiopia had such access in 2004. Rates of adult and youth literacy, school enrollment ratios, and spending on education, health and health facilities are generally low. With a primary school completion rate of only 37 percent of the relevant age group in 2000, 61 percent of Ethiopian adults are illiterate. In general, the rural population is endowed with few and poorly provided social amenities.

The comparisons above illustrate the disparities in rich versus poor countries in general, and Ethiopia in particular. The Ethiopian agricultural sector is especially problematic. Due attention should be given to this sector for two reasons: first, agricultural growth and development among the rural population is an important, and arguably an essential, component of the country's economic growth strategy. Second, in societies such as Ethiopia where a large majority of poor people live in rural areas, policies intended to improve this situation should give due attention to improve agriculture.

1.2 Justification of the Study

Todaro (1989, pp. 290-291) writes, "If 'development' is to take place and become self-sustaining, it will have to start in the rural areas in general and the agricultural sector in particular." Blanchard, as quoted by Todaro (1989), reasserts that "The main burden of development and employment creation will have to be borne by part of the economy in which agriculture is the predominant activity; that is, the rural sector." Todaro (1989) also quotes Myrdal's view that "It is in the agricultural sector that the battle for long-term economic development will be won or lost." More recently, Irz and Roe (2005), using a Ramsey framework, show that a small difference in agricultural productivity has drastic implications for the rate and pattern of growth of an economy. In this respect Hayami and Ruttan (1985, p. xix) express dissatisfaction over the fact that although a consensus seems to have been reached about the critical importance of agriculture to economic growth, it has remained outside the concern of most growth economists.

One can question the reason why purposeful policy action to facilitate growth in this sector is required. Agriculture is not only a source of employment for the majority of people in such countries but also provides other sectors with cheap food and serves as a market for the production forthcoming from other sectors. Farmers can also invest in other sectors, and as labor productivity in agriculture grows, the sector can supply labor to other areas of the economy. Due to the nature of the activity, farmers live in dispersed locations, which makes it hard for them to collectively address problems arising from imperfect markets or to promote their interests, thus making government intervention on farmers' behalf imperative.

What is required to transform peasant agriculture? Several authors suggest sets of policies that vary in emphasis and composition. Mosher (1966) puts markets, dynamic technology, availability of supplies and equipment, incentives for farmers, and transportation as the elements that constitute the essentials of agricultural development, and includes five other elements in the 'accelerators' group. Mellor's (1966) work also emphasizes a similar but more exhaustive set of factors to modernize agriculture. Hayami and Ruttan (1985), focused on constraints to technical innovations and adoption in agriculture. Extending this same idea to encompass the entire economy Parente and Prescott argued in their 2000 book, *Barriers to Riches,* that differences in international incomes are the results of differences in total factor productivity (TFP), which in turn are the result of country specific barriers/policies that cause "constraints in work practices and on the application of better production methods at the firm level" resulting in “differences in the knowledge individual societies apply to the production of goods and services.” (Parente and Prescott 2000, pp.1-2).

As noted above, many have argued in support of improving agricultural productivity in societies where a large majority of poor people live in rural areas. In this respect, reducing the incidence of poverty has become an important global issue. This is apparent from such widely publicized efforts as the Millennium Development Goals (UN 2004). The increased influence that international agencies have had on governments in poor countries means that administrations in developing countries are under pressure to reconsider their economic policies (Stiglitz 2003). Recent literature shows that pro-poor growth policies or policies that favor those living in poverty or are targeted towards reducing poverty, are often desirable not only from a humanitarian perspective but also because of their long-term economic growth consequences. For example, Dorward et al. (2004) showed the complementary relationship between growth in agriculture and non-agriculture sectors on the one hand, and between growth-promoting and welfare-supporting policies on the other. The authors conclude that in addition to largely benefiting poor people, short- to medium-term agricultural growth creates potential synergies between welfare support and growth. Empirical studies also show the key role of agriculture in reducing poverty. Boccanfuso and Kabore (2004), in a Burkina Faso study, conclude that sectoral growth, especially growth in agriculture and particularly the food crop sub-sector, contribute more to the decline in poverty than stronger macroeconomic growth. In a study of Tanzanian macroeconomic policies, Danielson (2004) finds similar results, and questions why agriculture is not the focus of the official poverty reduction policy in Tanzania.

In this thesis, using the Ethiopian economy as a basis for the analysis, I pursue the ideas broached above by way of first describing the general features of the Ethiopian economy and providing a detailed overview of Ethiopian agriculture using aggregate, agroecologic, and household level data. Next, I empirically assess the roles played by traditional sector-specific versus modern inputs in promoting agricultural growth in Ethiopia.

Complementing this growth assessment is a study of the sources of variation in the estimated efficiency of farm households included in a pooled series of Ethiopia Rural Household Surveys. The objective is to identify the more important components of stimulating traditional agriculture, thereby informing policy makers in their efforts to improve the livelihood of the majority of Ethiopians who are still heavily reliant on agriculture. Addressing the generally grim conditions of the Ethiopian economy sketched above and fleshed out in more detail in chapter three is part of the justification for embarking on this study. Another is the contribution the study makes by undertaking the analyses described in the paragraphs above.

1.3 Objectives of the Study

Ethiopia's average annual growth in GDP was 4.3 percent per year during the period from 1992 to 2005; almost double the average growth rate of 2.2 percent per year during the 1980 to 1990 period. However, during the 1992-2005 period agriculture grew by an average of about 3 percent while manufacturing grew by 5.6 and services by 5.1 percent, respectively (WDI 2007). Despite the government's reform program that stresses agriculture led development, agriculture remains the lagging sector (Federal Democratic Republic of Ethiopia 2002). Overall economic growth has derived mostly from the service sector, and despite its much smaller size in terms of employment, the industry has matched agriculture's contribution to overall economic growth. Moreover, Easterly (2004) argues that the underlying permanent growth during this period is overstated, as it contains some element of recovery from the civil war that preceded the period.[5] He calculates a permanent component of annual per capita growth of 1.1 percent during the 1992-2001 period, and indicates that the per capita income in 2001 was still at a level first attained in 1978. He concludes that the modest permanent component of growth after 1992 suggests that further action is needed to promote accelerated growth.

[5] This is evident from the level of growth rates for agriculture, manufacturing, services and the aggregate GDP for the year 1993; the respective growth rates were 6.1, 49.1, 17.6 and 13.4, while they all were negative for the year 1992.

von Braun et al. (2004) suggest 'progressive policy actions' to reduce and/or eliminate the increase in the number of undernourished people in developing countries. This policy environment requires, among other things, increased investment in rural development, health, education, better infrastructure, agricultural research and development, and dissemination of improved technologies. The literature supports this optimistic view that policies supporting agricultural and rural development can lead to significant improvement and in some instances to complete eradication of extreme poverty. Thirtle et al. (2001) show that out of the 291 million Sub-Saharan Africans getting by on $1 per day, 2.1 million could be taken out of their poverty if agricultural yield is increased by 1 percent, at a cost of less than $0.5 per day. They conclude that growth in agricultural productivity has a substantial impact on poverty reduction, whereas productivity growth in industry and services do not. Hanmer and Wilmshurst (2002) find evidence that the overall growth rate is likely to be as fast with broad-based (pro-poor) growth policies as with inequitable growth. Using 24 household sample surveys spanning 35 years in India, Datt and Ravallion (1998) find that higher farm productivity brought both absolute and relative gains to poor rural households through wages and prices and that such benefits to the poor were not confined to those near the poverty line.

In line with the evidence presented so far, this study argues that the grave problems faced by agrarian households in Ethiopia can be mitigated through appropriate socio-economic policies that favor peasant agriculture. In addition to constituting the largest share of consumers' budget, production in this sector is labor intensive, requires relatively less skilled labor, can be vertically integrated with comparative ease, has less of a capital component, and importantly, the largest proportion of the poor in such economies live and work in rural areas where peasant agriculture is the dominant sector. I also argue and show that investment in rural infrastructure, social services, agricultural extension, and institutional improvement contribute to increased agricultural output and reduced poverty.

The general objective of this work is to inform and thereby guide policy makers to find the areas they should emphasize in their effort to reduce poverty and promote long term growth. The objective of my analysis is to develop a framework that attributes growth in agricultural output and farm level inefficiency to its various sources.

In this study I intend to show that the factors that contribute to agricultural transformation in Ethiopia can be categorized in to three major groups: technological, institutional and infrastructural. These three groups are not mutually exclusive. The rationale for such classification is to emphasize what the factors represent, and to give focus for their policy implications.

- Technological factors include agricultural extension, education, and number of extension agents serving a peasant association.

- Institutional factors are taken to represent the government’s attitude and response to the declining agriculture by the type and strength of institutions it forms. Peasant associations, institutions that provide social services (health, education, clean water, and other social services), and others that lead to lower transaction costs and reduce information asymmetry, and institutions that promote rural welfare are included in this category.

- By infrastructure, I mean the extent of provision of facilities including roads, electric lines, bridges, and most notably, irrigation schemes.

In this study I examine if, and to what extent, the factors listed above contribute to growth in agricultural production, and their absence contributes towards reduced efficiency in Ethiopia. Such an analysis helps to identify the sources of possible improvement in the lives of the majority of Ethiopian farmers by indicating the implications of using alternative policy instruments to facilitate such growth.

2. SOURCES, DESCRIPTION AND PLANNED USE OF DATA

2.1 Sources and Description of Data

In chapter 3 I use household, agroecologic zone, sectoral- and macro-level data from the Food and Agricultural Organization of the United Nations (FAO), the World Bank, the Central Statistical Authority [of Ethiopia] and from the Ethiopian Rural Household Survey (ERHS) to draw a clear picture of the economy while giving attention to the agriculture sector. In chapter 4 I investigate the possible sources of output growth and reduced efficiency in subsistence agriculture in Ethiopia using household level data and aggregations from five of the six rounds of Ethiopian Rural Household Survey (ERHS).

The ERHS is a longitudinal household data set that includes about 1,480 households in 15 *woredas* (or districts) of rural Ethiopia. These households were surveyed during the 11-year period that spanned from 1994 to 2004. Ethiopia is divided into 13 language-based and 2 special (federal) regions. The two federal regions, Addis Ababa and Dire Dawa are the two largest cities in the country. The surveys span six of the remaining 13 regions. The largest proportion of the country's predominantly settled farmers are located in these six regions. The document that describes the first four rounds of data, which are publicly available, states that although these data sets are not nationally representative, they can be considered as broadly representative of households in non-pastoralist farming systems (Dercon and Hoddinott 2004). Regions, Zones, Woredas, and Peasant Associations (PAs) represent the hierarchy in the country's administration system. The surveys cover 15 of the 389 woredas in the six regions.[6] One Peasant Association was selected from each of the woredas except for one large woreda in the Amhara region, Debre Birhan, from which four Peasant Associations were included in the sample. The survey rounds are conducted on a sample that was stratified over the country's three major agricultural systems (Dercon and Hodinott 2004, p. 7), and the distribution of the

[6] There are five regions in SNNP, which stands for Southern Nations, Nationalities, and People. Three of the five regions were included in the survey.

households in terms of administrative regions is given in Table 2.1. These woredas are classified into five agroecological zones. The first agroecological zone is known as Northern Highlands. This zone includes two villages from the Tigray region, Geblen and Harresaw, and one village from the Amhara region, Shumsheha (Figure 2.1). The Northern Highlands are, in general, known for their poor natural resource endowments, especially their adverse climatic conditions and frequent droughts. The Central Highlands agroecological zone includes Dinki, Yetmen, and Debre Birhan woredas from the Amhara region, and Turufe ketchema from the Oromia region. The Arussi/Bale agroecological zone includes Koro Degaga and Sirbana Godeti woredas, both from Oromia. Adele Keke is a woreda located in the Oromia region and is the only woreda selected to represent the Hararghe agroecological zone. The remaining five woredas of Imdibir, Aze Deboa, Gara Godo, Adado, and Doma make up what is know as the Enset growing agroecological zone.[7] These five woredas are located in Southern Nations, Nationalities, and People region.

Table 2.1 Area and household coverage of Ethiopian Rural Household Surveys

Region	Population (in millions), July 2005[a]	Number of woredas in region[c]	Number of woredas included in all rounds[d]	Number of PAs included in all rounds[d]	Number of households surveyed[b]
Tigray	4.2	34	2	2	150
Amhara	18.6	109	4	7	479
Oromia	25.8	189	4	4	404
SNNP[e]	14.5	95	5	5	441

Sources: a. CSA (2007).

b. Ethiopian Rural Household Survey one (1994)

c. Central Agricultural Census Commission (2003).

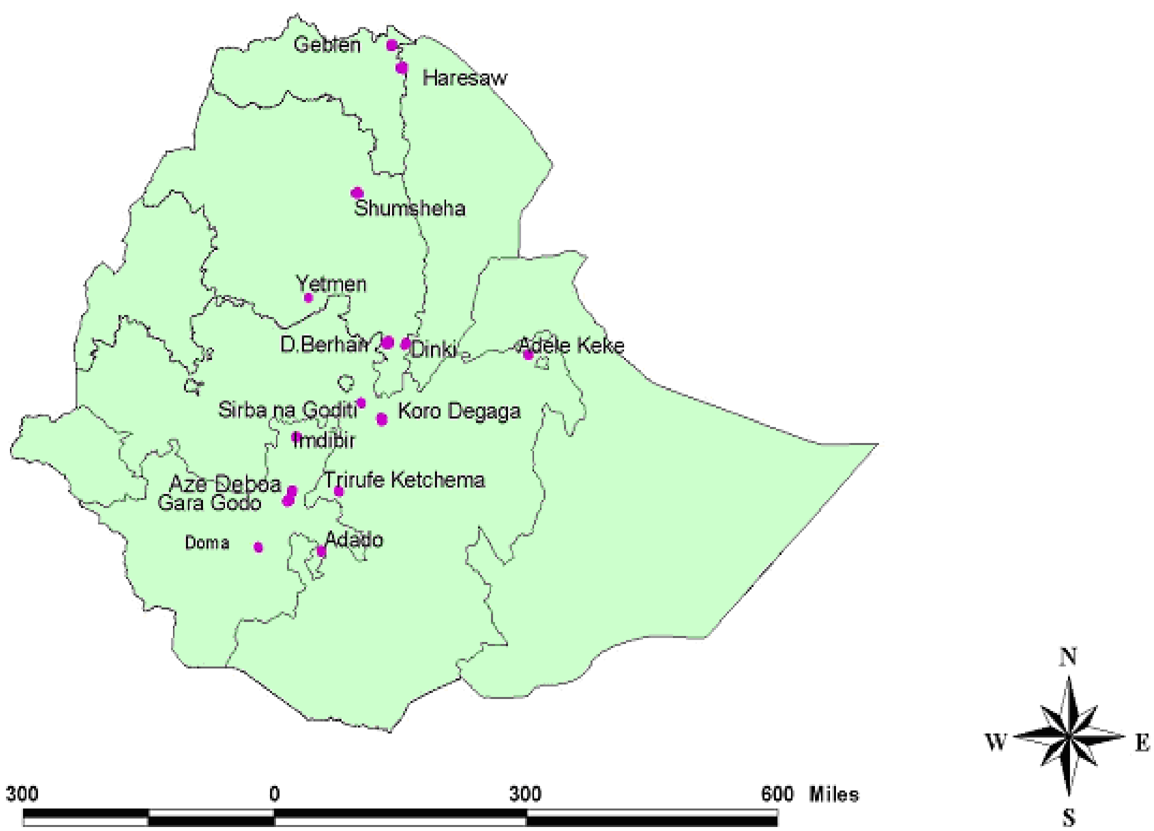
d. Ethiopian Rural Household Survey rounds one through six.

Note: e. While Tigray, Amhara, and Oromia are homogenous in the language composition, SNNP is formed out of five smaller regions.

[7] Enset, *scitamineae musaceae enset*, also known as the false banana, helps to feed approximately ten million people in Ethiopia and was given the status of national crop by the Ethiopian government. The bread that is made from enset is a staple diet in South Western Ethiopia while it is occasionally used in other parts of the country. Notwithstanding that South Western Ethiopia is one of the most densely populated regions in the country, it was able to withstand the famine of 1980s largely by cultivating this crop. (American Association for the Advancement of Science 2007)

The ERHS data used in this study were collected by a collaborative team that included individuals from the Economics Department, Addis Ababa University (AAU), the Center for the Study of African Economies (CSAE), University of Oxford, and the International Food Policy Research Institute (IFPRI). Funding for data collection was provided by the Economic and Social Research Council (ESRC), the Swedish International Development Agency (SIDA) and the United States Agency for International Development (USAID); the preparation of the public release version of these data was supported, in part, by the World Bank. AAU, CSAE, IFPRI, ESRC, SIDA, USAID and the World Bank are not responsible for any errors in these data or for their use or interpretation.

Figure 2.1 Peasant associations included in Ethiopian Rural Household Surveys



Source: John Hoddinott, personal communication (2009).

The ERHS is part of a capacity-building project for Ethiopia under the supervision of AAU, CSAE, and IFPRI. Dercon and Hodinott (2004) note that the genesis of this data collection effort was in 1989, when a team from IFPRI visited six farming villages in Central and Southern Ethiopia. The 1994 survey, considered the first formal round of the survey, included 15 villages located across the country.[8] A second round was conducted in late 1994; with third, fourth, fifth and sixth rounds collected in 1995, 1997, 1999 and 2004, respectively. The second round survey lacks some variables that are critical for this thesis (such as area of cultivated land per household). Since the survey was mostly an end-of-year repetition of what had been collected earlier that same year it is excluded from this analysis. I also opted not to use the 1989 data; it was difficult if not impossible in some instances, to create measures of variables that were comparable with those developed for later years in the series. In fact, the 1989 data were essentially collected as a one-shot undertaking, while other surveys were collected with follow up surveys explicitly in mind (Dercon and Hoddinott 2004). In the following paragraphs I describe the remaining data sets that span the period 1994 to 2004.

In each of the surveys, the questions are clustered into three or more parts that deal with a set of similar issues. All of the survey rounds contain a core of common parts, although the sections in each of the parts varied from one round to another. For instance, all six rounds have a part that is devoted to agriculture but the number of sections and sub-sections included, and the depth and type of questions vary from one round to another. Appendices 2.A.1 through 2.A.5 list subsections included in the agriculture section of each round of survey.

In addition to agriculture, the first round includes two additional sections; specifically, household demographics, assets, and non-agricultural income, along with food consumption, health, and women's activities (Table 2.2). The third round is exactly the same in structure as the first round although it also includes explicit questions on livestock. The fourth round adds data on two more sections. These include a family and

[8] In Ethiopia, the smallest unit of aggregation is the Peasant Association, an administrative unit of one or a small number of villages.

Table 2.2 Structure of Ethiopian Rural Household Surveys

Survey		Number of households		
Round	Year	Surveyed	With positive cultivated land	Parts included in the survey
One	1994	1,477	1,369	I. Household demographics, household assets, and non-agricultural income. II- Agriculture. III- Food consumption, health, women's activities.
Three	1995	1,480	1,305	I. Household demographics, household assets, and non-agricultural income. II. Agriculture and Livestock. III. Food consumption, health, women's activities, fertility.
Four	1997	1,418	1,331	I. Household demographics, household assets and non-agricultural income. II- Agriculture. III- Food consumption, health, women's activities. IV. Family and Marriage history. V. Community work and Public works
Five	1999	1,680/1,335[a]	1,224	I. Household demographics, household assets, and non-agricultural income. II- Agriculture. III. Food consumption and health.
Six	2004	1,372	1,257	I. Household demographics, assets and non-food expenditures, credit, and poverty perceptions. II- Agriculture. III- Food consumption, health women's activities. IV. Shocks, public works, drought, networks, Iddir, and trust.

Source: Ethiopian Rural household Surveys 1, 3, 4, 5, and 6.

Note: a. Round five included 3 peasant associations that are not surveyed in other rounds, the number of households, including the 346 households in these 3 peasant associations is 1,680, while this survey includes 1,335 households that are included in the other rounds.

marriage history, plus a community work component, along with a public works section. The fifth round has the three sections that were included in the first round while the sixth round adds a fourth section called Shocks, Public Works, Drought, Networks, Iddir, and Trust.[9] Each part deals with several related issues; for example, in the agriculture and livestock part there are sections that deal with perennial or permanent crops, agricultural implements, and spending on inputs. Appendices 2.A.1 through 2.A.5 list the sections that are covered in the agriculture and agriculture cum livestock sections of the five rounds.

The first round included 1,477 households, and rounds three to six involved 1480, 1,418, 1,681/1,335,[10] and 1,372 households, respectively.[11] The panel series that constitutes the basis for this study includes only households that cultivate a positive amount of land since an important objective of the study is to determine the sources of output growth and inefficiency in sedentary agriculture.[12] The resulting number of cases for each of the rounds is given in the fourth column of Table 2.2. The panel data set consists of a total of 6,486 observations.

2.2 Data Errors and Corrections

Data on measured inputs and outputs were collected mainly in local units in all rounds of ERHS. Different rounds comprised different local units. For instance, in addition to hectares 17 local measurement units were used in ERHS round 4 to measure cultivated area. There are two evident problems in using these units. First, only few of the local units are easily comparable with standard units and the same local unit may translate into

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[9] Iddir is a traditional cooperative arrangement that helps households during hardship, notably a loss of a family member.

[10] Table 2.2 footnote a clarifies the meaning of these two numbers.

[11] In these surveys households attrited are not replaced; that is, the panel data contains different households in each round. John Hoddinott confirmed that the survey protocol stated that households attrited between the 1989 and 1994 surveys were to be replaced, while those that dropped out between other rounds were not replaced. IFPRI is presently analyzing the statistical implication of these sampling issues. Preliminary results indicate that there is no self selection of households that drop out of these surveys.

[12] Kiremt is Amharic for the summer season, while Meher is the agricultural season that experiences kiremt rains in the months of June through September. Belg is the agricultural season that experiences less intense rains of February to May. (Institute for the Study of Society and Environment 2005)

different standard units while used by households residing in different peasant associations. Second, some of the local units do not even measure what is sought to be measured. For instance, a local unit used to measure area actually measures length, not area, and a local unit used to measure weight actually measures volume, not weight.

Conversion of household level measured inputs and outputs into standard units was conducted using conversion factors provided by IFPRI along with the official version of ERHS data. The conversion factors take into consideration peasant association level differences when converting local area and weight units into standard hectare and kilogram units and correct for inaccurate local measuring units used to measure area and weight. After converting measured inputs and outputs in to standard units, I used nominal prices collected at each round of survey to convert the output produced on each plot of land cultivated by each household into value of output.

As a third step, I aggregated up to a household level the area of plots cultivated by the household and the value of output produced on each plot. This aggregation is required because most of the ERHS rounds provide data on the remaining measured inputs only at a household level, making it difficult to associate the factors of production used to produce the output on each plot of land. Initial descriptive analysis revealed data problems that may have resulted from using local units, added with erroneous reporting by households as well as erroneous recording by interviewers. I closely studied the descriptive values of each of the variables and their frequency distributions, and focused on those values that looked suspicious. Some of the obvious problems involved coded values. For instance, if a coded variable can take either 1 or 0, a value of 2 is clearly erroneous. However, the more problematic entries involved value of output, area of cultivated land, and the amount of other measured inputs, such as fertilizer. I decided to concentrate on those values at the top and bottom of the frequency distribution of each variable and pick those households that looked inconsistent in terms the relationship between value of output, area of cultivated land, and the amount of inputs applied.

For example, data from households that came under close scrutiny included a household that used 3,000 kilograms of fertilizer on 0.38 hectares of land, a household that cultivated 27.25 hectares of land in 1995, while it cultivated only 2.98 hectares in 1994, 2.75 in 1997, 2.25 in 1999, and 2.25 in 2004. The only value of output that was smaller than the value of output harvested from the 27.25 hectares was from the 2.98 hectares of land cultivated in 1994. These are illustrative of the problems identified in a list that included over 100 entries. I suspected that there were other erroneous entries that I was not able to detect. This was evident from the results of my initial estimations of the stochastic production frontier parameters. These analyses were conducted after correcting a variable considered erroneous in a given year using such an ad hoc approach as substituting it with its average from other years. At that point I recognized that I needed further assistance from researchers that worked on the data. Although my previous communications with Dr. John Hoddinott and Yesehaq Yohannes of IFPRI proved to be invaluable, my stays at IFPRI in late 2006 and early 2007 were pivotal in remedying the problems.

Through the years researchers at IFPRI developed mathematical codes that treat problems associated with each of the variables separately for each of the rounds. This includes, but is not limited to, converting measuring units that are reported in a specific peasant association into what is commonly used in that peasant association if the reported unit is not commonly used, converting into commonly used local area measuring unit if a household reported cultivating multiple "gashas" of land, as there are no farmers that own such large plots of land in the surveyed peasant associations (a "gasha" is a local area measuring unit which translates to 40 hectares). Such corrections, which were based on practical experiences, improved the quality of the data immensely, as was evident from the initial parameter estimates of the stochastic production frontier and from the descriptive analysis of the data that used the corrected version. In addition to helping correct the data, colleagues at IFPRI provided peasant association and agroecologic specific data that were not released with the official version of ERHS data. At a later stage of this study I converted value of output of each household, which was given in nominal terms, into real value output. For that purpose I used peasant association level food price indices to deflate the value of output of farm households included in the surveys. Data on the food prices were purposefully collected and food price indices were calculated as a Laspeyers index, based on peasant association prices using average shares in 1994 as the weights.

2.3 Deploying the Data

Chapter three is devoted provides a detailed picture of Ethiopian agriculture. I use macroeconomic, agricultural, and agroecologic level data from CSA in conjunction with household level data from the five rounds of the ERHS. I also use data from the Food and Agricultural Organization of the United Nations. I used the 1999 (round five) data in isolation for a similar, but more in depth investigation, as it is unique in many respects. The data set from this round, unlike other rounds, has disaggregated information on all inputs used and the outputs produced on the different plots cultivated by each household. All other rounds report household level data on all inputs except area of cultivated land and on the amount of output produced on each plot that the household cultivates.

Using aggregated data from rounds 1, 3, 4, and 6 together with similarly aggregated round 5 data will provide the richness that one can find from a panel data while using round 5 data separately will entail the advantage of the disaggregation, and will be helpful to investigate the sources of difficulties in transforming small scale farmers as this round of data contain unique information on modern input uses of the surveyed households. In addition to ERHS data I will be using several other sources.

3. AGRICULTURE IN ETHIOPIA

3.1 Introduction

According to the Central Statistical Authority, hereafter CSA, Ethiopia's estimated gross national product (GNP) at market prices was 183.5 billion birr ($20.6 billion) in the 2007 fiscal year (FY).[13] Real GDP grew by 11.4 percent between FY 2006 and 2007. In FY 2007, spending on gross fixed capital formation constituted 23.2 percent of the GNP, 77.8 percent of the GNP was spent as private consumption, and 10 percent as government consumption expenditure.[14] Exports and imports were 12 and 30 percent of GNP, respectively, with imports well more than double the value of exports.

Agriculture, manufacturing, distributive and other services constituted 46, 13.3, 21.3, and 19.6 percent of GDP, respectively.[15] The rise in real GDP between 2006 and 2007 FYs is mainly due to growth in agricultural GDP (AgGDP) and the value of distributive services. At 1980/81 constant factor cost, AgGDP and distributive services rose by 9.4 and 15.7 percent, respectively, between the 2006 and 2007 fiscal years.

In FY 2007, the government's total domestic revenue was 21.7 billion birr while external grants amounted to 8.4 billion birr, which grew by 80 percent over previous year's external grant. Total government spending during the same fiscal year was 36.8 billion birr, incurring a deficit of 6.7 billion birr. In the same year 18.3 billion birr was allocated to government recurrent expenditure out of which only 12 percent was spent on economic services. The largest share of the spending, 38.4 percent, was allocated to what is grouped as general services, which includes spending on defense and other government bodies.

[13] In Ethiopia the fiscal year ends on 7th July. The fiscal year 2007 ran from 8th July 2006 through 7th July 2007. In this section I use CSA's statistical Abstract (CSA 2008) unless stated otherwise. Birr is Ethiopia's national currency. For the fiscal year 2006/7 the average marginal exchange rate at the foreign currency auction that is held once per two weeks at the National Bank of Ethiopia was about 9 birr per US dollar while the average parallel market rate was 9.5. (National Bank of Ethiopia 2008).

[14] The excess of the sum of these percentages over 100 percent is covered by the excess of imports over exports.

[15] Distributive services includes merchandise trade, hotels, restaurants, transport, and communications while the category 'other services' includes finance, insurance and real estate, public administration, defense, education, health, and other domestic services.

Among these the largest spending was on defense, which was about 16.4 percent of total recurrent spending, 37 percent higher than the aggregate spending on economic services. Spending on agriculture constituted only 9.2 percent of the total government recurrent spending, about one-half of the spending on defense. Capital spending accounted for about 50 percent of the total government spending. Capital spending on economic development constituted about 62 percent of the total capital spending, although the absolute amount, about $1.3 billion, is comparatively small.

3.2 An Overview of Ethiopian agriculture[16]

Agriculture is a major contributor to the country's GDP, export earnings, and is a source of employment to the fast growing population. However, the sector uses little modern inputs and output per hectare is low. With the rural population increasing at a fast pace, land holdings have been increasingly fragmented, resulting in a large proportion of small land holdings, each with little, if any, capital investment.

3.2.1 Input Use[17]

Central Agricultural Census Commission, hereafter CACC, data indicate that in the 2001/2 main agricultural season, over 54.5 million Ethiopians derived their livelihood from agriculture.[18] Moreover, 55 and 34 percent of the rural population were below the age of 18 and 10, respectively, indicating that in future years an increasing number of Ethiopians are likely to depend on agriculture. In 2001/02 there were 10.4 million agricultural households: 17.6 percent of the households had female heads, and average family size in female- and male-headed households was 3.8 and 5.4, respectively.

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[16] Unless otherwise stated I use four references in this section: 1) Central Statistical Authority (2007)[a], Central Statistical Authority (2007) [b], Central Statistical Authority (2008), and Central Agricultural Census Commission (2003).

[17] I use census data from CACC (2003) in the labor subsection of this section and in section 3.2.2 as the data provides rich insights and recent census data are unavailable.

[18] In the 2007 main agricultural season, about 60.6 million Ethiopians resided in 11.75 million rural households. About 12 million of these people owned a total of 14.74 million hectares of land, which on average is 1.25 hectares per household and 1.21 hectares per farmer. The average household size was 5.2. Hereafter, unless otherwise stated all data refer to the main agricultural season.

Labor

In the 2001/2 main agricultural season, there were 35.8 million people aged 10 and above residing in rural areas, 73 percent of whom were actively working.[19] This working population consisted of 85 percent of males and 61 percent of females, and 81 percent of the total worked full-time in agriculture, 17 percent worked in agriculture on a part-time basis, and 3 percent worked non-agricultural jobs. The employment split varied between males and females, as most women did not own land. Forty two percent of females worked on full-time basis in agriculture, 38 percent worked part-time in agricultural jobs and 20 percent worked in non-agricultural jobs. The corresponding numbers for males were 82, 16, and 2 percent. Out of those working in agriculture 56 percent were unpaid workers working on family farms, 38 percent worked on their own farms, 3.6 employed others to work for them while 2.6 were employed by others (CACC 2003). Thirty two percent of rural residents aged 10 and above owned land; and 64 percent of these landowners were illiterate. The ratio of illiterate landowners is almost identical to the rate of illiteracy among all rural residents. While 53 percent of male rural residents were illiterate, 78 percent of females residing in rural areas have no formal or informal education (CACC 2003).

Table 3.1 Literacy and employment rates among adult rural residents

Rural residents aged 10 and above	Percent
Own Land	32
Literate out of those that owned land	36
Literate land owners with primary education	5.3
Male literacy	47
Literate males with primary education	6.3
Female literacy	22
Literate females with primary education	2.5
Male employment	85
Female employment	61

Source: CACC (2003).

[19] According to CACC (2003) a person is deemed to be working when they are participating in the production of goods and services.

As one might expect the share of the non-working population is higher at the upper and lower ends of the age distribution; 41 percent of those aged 10 to 17 years and 26 percent of those above 50 years of age were not working. The 30 to 40 year age group had the lowest non-working share at 16 percent. Even if males and females constituted almost equal shares of the total rural population of ages 10 and above, the percentage of females not-working at 39 percent is more than twice that of males at 15 percent. Unemployment among females is more than twice the rate of males for all ages except for those between 10 and 17 years in which 33 percent of boys and 50 percent of girls of this age group are not working. Out of the 6.9 million females that are not working, only 19 percent attend school while 66 percent are homemakers. Out of the 2.8 million males that are not working 70 percent are attending schools while 10 percent are homemakers (CACC 2003).

Land Use

In the 2006/7 main season 12.2 million of the 60.6 million rural residents, or about 20 percent, owned a total of 14.74 million hectares of land, while the remaining 80 percent were related to those who owned land (CSA 2007[b]). Although land ownership among women grew at an average annual rate of 1.4 percent between 2001/2 and 2006/7 agricultural seasons, only 20 percent of landowners are women, and about 2 percent were under the age of 18. Out of the 14.74 million hectares of land 85 percent was self operated, 11 percent was rented and 4 percent operated under other arrangements. A reported 10 percent of the farmers used their land exclusively for crop production, less than 2 percent used it only for livestock production, and the remaining 88 percent engaged in mixed cropping and livestock operations (CSA 2007 [b]).

Out of the 14.74 million hectares of agricultural land operated by private farmers in the 2006/7 agricultural season, close to 11 million hectares, or 74.4 percent, was used to grow temporary crops, 6 percent or 823,000 hectares was under permanent crops, 6.7 percent was used for grazing, 9.8 percent was fallowed, and the remaining was left as

Table 3.2 Utilization of agricultural land in 2001/2 and 2006/7 agricultural seasons

Utilization of land	Size utilized (in 000 hectares)	
	2001/2[a]	2006/7[b]
Total agricultural land	11,000	14,744
Land under annual crops	8,200	10,965
Perennial crop	668	823
Grazing land	957	987
Fallowed land	836	1,444
Woodland or other uses	385	525

Sources: a. CACC (2003), summary Table IV.3.
b. CSA (2007 [b]), Table 1.

woodland or put to other uses (CSA 2007[b]). Comparing the 2001/2 and 2006/7agricultural seasons, more land had been brought into use in 2006/7 across every category. No doubt the increase in the rural population, combined with a portion of 55 percent of rural residents who turned 18 since 2001/2 caused the demand for agricultural land to increase. The structure of land use changed little between the two seasons, except that the proportion of grazing land increased, while the proportion of land fallowed declined by 2 percent.

In the 2006/7 agricultural season, about 8.5 million hectares or 77 percent of the total area under temporary crops was sown to cereals. The area under pulses, oilseeds, root crops, and vegetables was 13, 6.8, 1.7, and 0.8 percent, respectively. Of the total area used for cereals, teff accounted for 28.4 percent followed by maize, sorghum, wheat, and barley accounting for 20, 17, 17, and 12 percent, respectively.[20] The order of importance of teff and other crops in terms of area allocated was almost the same between 2001/2 and 2006/7 main agricultural seasons (CSA 2007 [b]).

In 2006/7, 55 percent of the farms were one hectare or less, while less than 1.5 percent of the farms were larger than 5 hectares (Table 3.3). Smaller farm sizes are more common

[20] Teff, *Eragrostis tef*, is a cereal that has a tiny grain that is ground into flour, fermented and made into enjera, a sour-dough type of flat bread that is a staple food in a large part of Ethiopia. (Purdue University 2007)

among those who specialize in either crop or livestock production; 90 percent of livestock producers own farms that are half a hectare or less in size, as do 72 percent of crop producers (CSA 2007[b]).

Table 3.3 Landholders by size of ownership, type of activity and family size, 2006/7 agricultural season

Type of holding (Percent)	All holders	Size of holding in hectares					
		Under 0.1	0.10-0.50	0.51-1.00	1.01-2.00	2.01-5.00	Over 5.01
Number of farmers (000)	12,196	744	2,982	2,983	3,293	2,020	174
Percent	100.00	6.10	24.45	24.46	27.00	16.56	1.43
Crop only	10.14	18.73	42.63	21.29	13.77	3.48	0.09
Livestock only	1.85	78.05	10.35	6.52	4.31	0.75	0.00
Crop and livestock	88.01	3.13	22.66	25.20	29.00	18.40	1.61
Land distribution by family size							
Number of households (000)	11,750	665	2,748	2,869	3,232	2,047	189
Percent	100.00	5.66	23.39	24.41	27.51	17.42	1.61
One member	2.68	14.01	4.39	2.08	0.90	0.58	0.00
Two to three members	22.77	45.81	33.04	23.62	17.24	10.68	4.67
Four to five members	33.71	27.77	36.31	36.71	34.78	27.99	14.49
Six to nine members	37.01	11.52	24.68	35.14	43.00	53.21	56.30
Ten or more members	3.83	0.89	1.57	2.44	4.08	7.54	23.82

Source: CSA (2007 [b]), summary Tables 2 and 6.

Seventy one percent of the 11.75 million rural households have 4 to 9 members. Less than 3 percent are single-person households, while close to 4 percent have 10 members or more, the size composition of households varied little between 2001/2 and 2006/7. The lower part of Table 3.3 gives land distribution by household size. On average 53 percent of households farmed one or less hectares, while only 1.6 percent of households had farms larger than five hectares (CSA 2007[b]).

In Ethiopia, the Federal government owns all rural and urban land. Use rights for agricultural land are distributed among households by peasant associations according to structure of farm households. Accordingly, land redistribution occurs as family size and composition changes in the peasant association. Households are given the right to farm, rent for short periods of time, or sharecrop the land they are allocated. However, they have no right to sell land (Constitution of the Federal Democratic Republic of Ethiopia 1994). Land redistribution occurred frequently during the regime that governed the country from 1973 through 1991, while the current government instigated two land redistribution schemes since 1991 (Easterly 2004). Although the intent of these redistributions was to expand access to land, they may well discourage farmers from making investments in the lands they farm given the uncertainty of the duration of their tenure. As Table 3.3 shows, the size of land holdings increases with family size, in line with the intent of such land redistributions. Almost all single member households farm 2 hectares or less, and 91 percent of them farm 1 hectare or less. The proportion of households that own 1 hectare or less declines with family size. Households with 10 or more members have the largest proportion of large sized farms, with 36 percent of these households farming more than 2 hectares (CSA 2007[b]).

Modern Inputs: Fertilizer, Pesticides, Irrigation and Soil Conservation

CSA (2007[a]) reports that in 2006/7 405 million kilograms of chemical fertilizer was used on just 3.66 million hectares (31 percent) of the 11.8 million hectares of agricultural land used to grow temporary and permanent crops. In addition, 7.9 million farmers reported having applied natural fertilizer to 1.6 million hectares of land. Urea was used by 0.6 million farmers that applied 17 million kilograms of Urea on 0.20 million hectares of land, while 2.8 million farmers that use only DAP have applied 140 million kilograms of DAP on 1.75 million hectares of land.[21] Farmers that use both DAP and Urea constitute the largest number, 2.4 million farmers applied 247 million kilograms of DAP and Urea on 1.7 million hectares of land (Table 3.3). Of the total farmed area of 3.66

[21] Urea, also known as carbamide, is the first organic compound to be artificially synthesized from inorganic starting materials of carbon, nitrogen, oxygen and hydrogen. More than 90 percent of world Urea production is destined for use as a fertilizer. Urea has the highest nitrogen content of all solid nitrogenous fertilizers in common use and is highly soluble in water. It, therefore, has the lowest transportation costs per unit of nitrogen nutrient.
DAP is short for, diammonium phosphate, which is one of a series of water-soluble ammonium phosphate salts that can be produced when ammonia reacts with phosphoric acid. When applied as plant food, it temporarily increases the soil alkilinity, but over a long term the treated ground becomes more acidic than before upon nitrification of the ammonium. DAP is sometimes used as a yeast nutrient for brewing mead, and is an additive in some brands of cigarettes (Wikipedia 2007).

million hectares of land treated with chemical fertilizers, 92 percent was under cereals, 3.3 percent under pulses, and 4 other land use categories had about 1 percent each. Notably only five cereals (teff, maize, wheat, barley, and sorghum) accounted for more than 95 percent of the total fertilized land sown to cereals indicating that almost all the fertilizer use was dedicated to just few cereal crops (CSA 2007[a]).

In 2006/7, average chemical fertilizer use among those who used fertilizer was 110 kilograms per hectare while average fertilizer use on total cultivated land was 34 kilograms per hectare (representing DAP use of 21 kilograms per hectare, average Urea use of 1.4 kilograms per hectare, and combined DAP and Urea use of 11.8 kilograms per hectare, not shown in the table. Maize was the most fertilized crop at 137 kilograms per hectare, followed by wheat at 122 kilograms per hectare, and sorghum at 115 kilograms per hectare. Fertilizer supplied by the government accounted for 52 percent of the fertilizer used, small traders supplied 32 percent, and bigger private companies supplied 9 percent (CSA 2007 [1]). Just 45 percent of the total cultivated area received some natural or chemical fertilizer in 2006/7. The fertilizer application rates among those that used fertilizer is encouraging, suggesting that with proper incentives and institutions relatively intensive rates of modern input use can be achieved.

Fertilizer is the most widely used modern input. In 2006/7 just 3 percent of the total cultivated land was sown to improved seed. The average rate of improved seed use in the country was only 1.5 kilograms per hectare; however, among those that use improved seed the rate was 49 kilograms per hectare. Improved seed use is more common in the production of cereals than for any other crop. Nonetheless, only 4 percent of the area under cereals was planted using improved seed. Among cereals improved seeds use varies between 0.2 percent of the area planted to sorghum and 16 percent of the area planted to maize. Teff farmers rarely use improved seed, as only 0.5 percent of the area under teff was cultivated with improved seed. Farmers that use improved maize sow at a rate of 24 kilograms per hectare, compared with a sowing rate of 45 kilograms per hectare when indigenous seeds are used. Another important crop in Ethiopia is wheat, accounting for 17 percent of the total area under cereals, but only 3.2 percent of the area

Table 3.4 Area cover and rate of utilization of fertilizer, 2006/7 agricultural season

Crop type	All Crop Area (in 1000 hectares)	All Fertilizers			Natural		DAP		Urea		Urea and DAP	
		Area (in 1000 hectares)	Percent area	KG/ha[a]	Area (in 1000 hectares)	Percent area	Percent area	KG/ha[a]	Percent area	KG/ha[a]	Percent area	KG/ha[a]
All	11,788	5,271	44.7	76.75	1,609	13.6	14.8	80.2	1.73	83.65	14.5	144.5
Cereals	8,463	4,331	51.2	81.84	950	11.2	18.6	76	2.09	70.55	19.3	136.4
Teff	2,405	1,425	59.3	81.63	88	3.7	22.3	62.3	3.73	49.49	29.6	110.3
Barley	1,019	438	43	63.55	139	13.7	19.4	83	0.69	63.31	9.2	117.1
Wheat	1,474	1,051	71.3	111.9	91	6.2	32.1	90.2	1.76	84.67	31.3	157.7
Maize	1,689	961	56.9	79.74	402	23.8	12.9	83.9	1.72	121.59	18.5	175.4
Sorghum	1,461	261	17.9	26.18	202	13.8	1.3	90.6	1.16	98.61		
											1.6	148
Pulses	1,379	275	19.9	57.77	154	11.1	6.9	102.5	0.3	212.65	1.6	239.9
Oilseeds	741	76	10.3	125.28	36	4.8	3.1	109	0.76	76.74	1.6	568.7
Vegetables	95	66	69.7	86.73	35	36.8	11.2	137.1	4.48	122.63	17.2	230.7
Root crops	189	118	62.6	68.4	69	36.6	16.6	130.7	1.43	146.99	7.9	238.4

Source: CSA (2007[a]), Table 1.

Note: a - KG/ha refers to kilograms per hectare.

under wheat was cultivated using improved seeds at an average sowing rate of 187 kilograms per hectare. Overall, 50 kilograms per hectare of improved cereals seed was used, compared with 83 kilograms per hectare of indigenous seed (CSA 2007[a]).

The limited use of modern inputs extends to pesticides and irrigation. In 2006/7 only 2.8 million farmers (23 percent) used pesticides on 1.7 million hectares of land. That is, 15 percent of the area was treated with pesticides (CSA 2007[a]). Setting aside cereals and root crops, all other land categories had less than 5 percent of their area treated with pesticides. About 20 percent of the cereal area was treated with pesticides, ranging from 30 percent of the area under teff to 2.5 percent under maize. Despite the fact that a large portion of the area cultivated under each category suffered crop damages due to lack of pesticide use, the extent of pesticides use is limited. While 13 percent of the area cultivated with pulses reported disease, locust, frost, or flood damages in 2006/7, only 2 percent of this damaged area was treated with pesticide. Similarly, 15 percent of the area under oilseeds suffered some damage, but only 1 percent was treated with pesticides. In addition to the purchased inputs discussed above, about 9.8 million farmers (84 percent) used crop rotation to improve soil fertility during the 2006/7 season, over 4 million (35 percent) constructed terraces on their fields, 5.9 million (49 percent) ploughed their land along contours, 2.3 million (20 percent) constructed water catchments, and 0.35 million (3 percent) participated in afforestation (CSA 2007[a]).

Water is the most limiting input in Ethiopian agriculture. The average annual precipitation over the years 1993 through 2007 was 848 millimeters. Only 7 percent of the 11.7 million landholders irrigated their land in 2006/7 representing just 1.1 percent of the total cultivated land. Notwithstanding their significance to staple food crop production in Ethiopia, cereals, pulses, and oilseeds are poorly irrigated with only 0.8, 0.4, and 0.1 percent of the respective area under each crop receiving any irrigated water in 2006/7. That same year, teff, a crop cultivated on about 2.4 million hectares of land, had only 37,347 hectares or 0.4 percent irrigated. Less than one percent of all the other cereal area was irrigated, except maize where 2.4 percent of the cultivated area was irrigated. Perhaps not surprisingly, other high-valued crops such as vegetables, root crops, and perennial crops (which include most cash crops) are more heavily irrigated, but again the coverage is limited with between 3 and 7 percent of their cultivated area irrigated. Rivers provide the water for 65 percent of the farmers that irrigate. About 10 percent farmers get their irrigation water from ponds and 5 percent from lakes, with about 20 percent of the farmers securing water from a variety of other sources including wells.

At first glance a lack of education appears not to be an especially limiting factor in terms of farmers' openness to using modern inputs. In 2006/7, among those who applied fertilizer, 60 percent were illiterate, while 60 percent of those who were literate had only primary education, and 17 percent had any education beyond primary school. Similarly, among those who used improved seeds, 54 percent were illiterate, and only 56 percent of those who were literate had primary education. The same pattern of education was evident for those who used pesticides and irrigated their land. Thus, notably, the percentage of farmers adopting modern inputs exceeds the percentage of illiterate farmers.

Participation in Extension Package

In 1993, at the time the country was recovering from the devastation of a protracted civil war, Sasakawa Global 2000, hereafter SG 2000, initiated a collaborative agricultural project with the Government of Ethiopia. In the first three years, SG 2000 established nearly 5,000 extension management training plots (EMTPs) in 67 woredas in four regions with high agricultural potential. The half-hectare EMTPs allowed farmers and extension agents to learn improved methods and witness first-hand the costs and returns from using modern inputs effectively. SG 2000, in its country report (Sasakawa Africa Association 2000) states that in 1995, based on outstanding results from the EMTPs, the Ethiopian government decided to apply the SG 2000 technology transfer approach on a large scale, and to also mobilize its own financial resources to support the endeavor. It launched the National Extension Intensification Program (NEIP) with the intention of ensuring the countrywide availability of inputs and credit for over 32,000 EMTPs. Most of the effort was targeted on maize production; in 1996 the NEIP was expanded to 320,000 plots.

With the government gradually assuming roles initially played by SG 2000, the Sasakawa Initiative has now shifted its attention to training extension agents, supporting research and extension on crops such as teff and quality protein maize, and support the expanded uses of crops such as cassava, including the introduction of agro-processing methodologies and training farmers on such processes (Sasakawa Africa Association 2000). More recently, SG 2000 has moved beyond promoting the extension program it launched in several countries (handed over such activities to state agencies), and has concentrated on tackling such health hazards as river blindness. In 2004, SG 2000 was actively involved in improving crop production through the introduction of water harvesting technologies in 15 districts of Ethiopia, which had contributed to increased income and reduced costs (Sasakawa Africa Association 2007).

In 2006/7 2.2 million farmers had reportedly adopted the farming methods and input use package introduced by SG 2000 and also promulgated by government's NEIP (CSA 2007[a]). These farmers constituted 17 percent of the total farmers in Ethiopia and farm 13 percent of the total landholding in agriculture. Similar to other inputs, the SG 2000 extension package was used mostly on cereals. The package was applied on 17 percent of the area under cereals, and 6 percent of the area under root crops. All of the remaining crop categories cultivated less than 3 percent of their cropped area using the package. Looking at specific cereals, 25 percent of the 2006/7 area under wheat cultivation used the package, followed by maize at 22 percent, teff at 18 percent, and barley at 12 percent (CSA 2007[a]).

In 2002/3 9.3 million or 93.5 percent the country's farmers did not adopt the package. About 36 percent of these farmers failed to adopt the package because they reportedly had insufficient funds to purchase the inputs, while for 26 percent of the farmers the program was not available in their area. Ten percent of the farmers do not have sufficient arable land to adopt the program, while 20 percent of the farmers were either ignorant or suspicious of the benefits of the package (CSA 2007[a]). Given the low percent of farmers adopting the package of inputs and their stated reasons for not adopting the package, the program does not seem to have achieved its goal. For example, the number of farmers that adopted the package in 2002/03 could conceivably have doubled if they had access to credit, while the number of farmers that were either ignorant or suspicious of the program was larger than the number of farmers using the program. Moreover, for every ten farmers who adopted the package, there were 14 others for whom the program has not been made available over the 1993-2004 period.

3.2.2 Yield and Utilization of Harvest

Between September 2001 and August 2002, an estimated 10.5 million metric tons of grain (cereals, pulses and oilseeds) was produced on 8.8 million hectares of land by 10.14 million landholders. Cereals accounted for 87 percent of this aggregate, pulses made up 10 percent, and oilseeds accounted for 2 percent of the total. The area sown to cereals constituted for 82 percent, pulses accounted for 13 percent, and oilseeds 5 percent of the total area used to produce grains. Farm households consumed 64 percent of the grain they produced, 13 percent was retained as seed, and 3 percent was paid out as wages, used as animal feed or put to other uses. Marketable output constituted only 20 percent of the total grain production. The proportion of marketed output varied from 15.7 percent in cereals, to 54 percent in oilseeds. Twenty two percent of pulses production was marketed. While the extent to which oilseeds are marketed makes the group equivalent in terms of marketability to such cash crops as coffee (marketed at 59 percent), and khat (63 percent sold off farm), the fact that only 15.7 percent of cereals are marketed indicates the extent of the subsistence nature of agriculture in Ethiopia. Cereals constitute the single most important crop category in terms of the area that they are sown to and the number of farmers engaged in their production (CACC 2003).[22]

[22] Khat, *catha edulis,* is an evergreen drought-resistant perennial shrub originating in East Hararghe, Ethiopia. It is a stimulant with a mild narcotic effect. Nowadays it is grown in east, west and south-west regions of Ethiopia. (Oxfam 2005)

Within cereals, the three most marketed crops are teff (26 percent sold off farm) and wheat and rice, both at about 20 percent. Farm households consumed three quarters of their production of maize, sorghum, and vegetables. About 65 percent of barley, and root crops production was used for household consumption. During the September 2001 to August 2002 period, out of a total of 373,247 hectares of land allocated for stimulant crops, 26 percent was planted to khat trees, 69 percent was planted to coffee, and 5 percent planted to hops. Although the area under coffee was about 3 times larger than the area under khat, and there were only 6 khat producing people for every 10 people producing coffee, the speed at which the production of khat is expanding in the established khat producing regions and being introduced to new areas - especially following the drastic fall in coffee prices - is of increasing concern to the government and international development agencies. Chewing khat is not welcome in many societies in Ethiopia and it is an illegal substance in the United States and some European countries.

During the one-year period extending from September 2001 through August 2002 average teff yield was 874 kilograms per hectare. Among cereals the highest yield of 1,829 kilograms per hectare was obtained from rice, which was planted on only 0.2 percent of the area sown to cereals. This is 215 times less than the area that was allocated for teff, and there were only 7 farmers growing rice for every 1,000 farmers growing teff. Another high yielding cereal was maize at 1,813 kilograms per hectare. Although the area under maize was less important than the area under teff, more farmers were engaged in maize production than in teff production. There were 7 million landholders cultivating maize in 2001/2002 agricultural season while 4.6 million farmers cultivated teff. There were 3.51 million farmers that cultivated barley, 3.50 million farmers cultivated sorghum, and 3.31 million cultivated wheat (CACC 2003). [23]

Throughout this description I considered the main agricultural season called “meher” as main reference. The other season, called “belg”, relies on the less intense rains that fall

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[23] These numbers are not mutually exclusive. A farmer may be engaged in the production of two or more items.

from February to May. The area subject to these rains is so small that there were only 3.5 million landholders that cultivated 0.86 million hectares of land with grains during the 2002 belg season, compared with 9.6 million farmers that sow 7.8 million hectares of land with grains during the meher season. In addition, average yields vary greatly between the two seasons. In contrast to the 874 kilograms per hectare of teff produced in the meher of 2001/2, the yield in belg of 2002 was 355 kilograms per hectare. Barley yields were 1,208 and 258 kilograms per hectare in the meher and belg seasons of 2001/2 and 2002, respectively. Likewise, wheat, maize and sorghum yields were 1,437, 2,116 and 1,365 in the meher versus 272, 717 and 570 in the belg season (CACC 2003).

3.3 A Comparative Analysis of Ethiopian Agriculture

A comparison of the rate of fertilizer use in Ethiopia with other countries indicates that farmers in Ethiopia use only a small proportion of the amount of fertilizer used elsewhere (Table 3.5). Ethiopian farmers apply fertilizer at a marginally higher rate relative to the group of the poorest five countries of Burundi, Democratic Republic of Congo, Malawi, Niger, and Tanzania.

A comparison of the fertilizer application rates in Ethiopia with application rates in the four neighboring agricultural countries of Kenya, Egypt, Sudan, and Uganda indicates how Ethiopia fares among countries with similar geographies and histories. Average fertilizer application rates in these countries have always exceeded the application rates in Ethiopia. Between 2002 and 2006 average application rates in Ethiopia were only 6 percent of the average rates applied in these four neighboring countries, the average for the 1961 through 2001 period was only 2.3 KGs per 100 KGs used in these four countries. In particular if we were to compare use levels in Ethiopia with that of Egypt the picture is grim.

Between 2002 and 2006 Ethiopian farmers on average applied only 1.6 kilograms of fertilizer per each 100 kilograms applied by Egyptian farmers on a hectare of arable land.

Table 3.5 Comparison of fertilizer use in Ethiopia with other countries and regions

Country or Group of Countries	Total fertilizer consumption per hectare				
	2002	2003	2004	2005	2006[a]
	Kilograms per hectare				
Use by poorest five[b]	5.57	5.79	3.86	7.3	8.41
Use by neighbors[c]	197.12	272.72	91.21	101.69	367.36
Ethiopia	10.28	3.66	12.98	8.09	10.39
	Proportions				
Ethiopia/Use by Poorest five	1.85	0.63	3.36	1.11	1.24
Ethiopia/Use by Neighbors	0.05	0.01	0.14	0.08	0.03
Ethiopia/Egypt	0.01	0	0.04	0.02	0.01

Source: FAO (2006).

Notes: a. Uses 2005 cultivated area

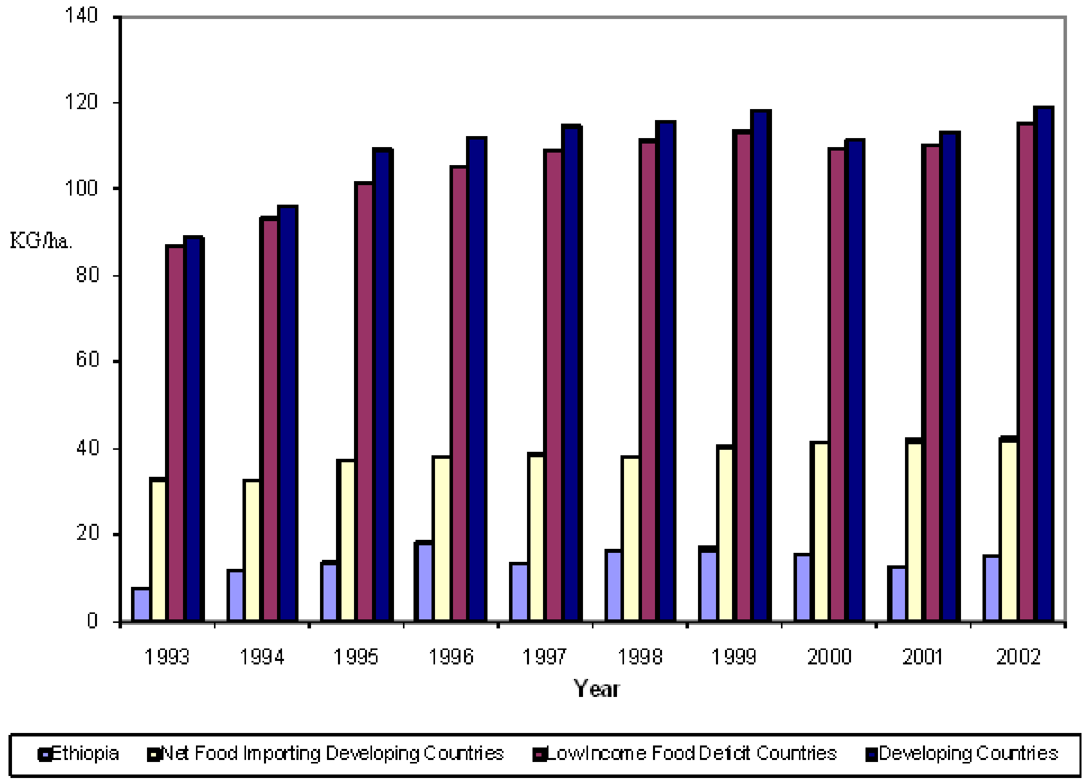
b. The poorest five countries area: Burundi, Democratic Republic of Congo, Malawi, Niger, and Tanzania.

c. The four neighboring countries are; Kenya, Egypt, Sudan, and Uganda.

During the 1961-2001 period Ethiopian farmers on average applied 0.6 KG of fertilizer on a hectare of arable land per 100 KGS applied by Egyptian farmers. Historic data from FAO ascertain that the relatively low rate of fertilizer application in Ethiopia holds true while comparing the use in Ethiopia with other groups of countries (Figure 3.1). Moreover, this low level of use of modern inputs was true also for different types of pesticides. Tractor use was also limited in Ethiopia. In 2002 there was about 1 tractor per 1,000 hectares of arable land in Sub-Saharan Africa, in Ethiopia there was about 0.3 tractor, that is, there were about four times as many tractors per 1000 hectares of arable land throughout Sub-Saharan Africa than in Ethiopia.

Ethiopia is not only the major source of the Nile River, but also has other major international and local rivers that can be used for irrigation. As shown in the previous section rain-fed agriculture has become increasingly undependable in Ethiopia. In an economy where 85 percent of the population is engaged in rain-fed agriculture and where drought had recurred for the past three decades, irrigation is an important way to improve the lives of many, if not most, of Ethiopians. Developing irrigation infrastructure can play an important role in the effort to improve this sector. FAO estimates that in 2003

Figure 3.1 Relative fertilizer use (KG/hectare) in Ethiopia and groups of developing countries



Source: FAO (2006).

Ethiopian farmers irrigated only 2.6 percent of the arable land. This number was lower than the one in any of the groups of comparable countries. The share of arable land irrigated by Ethiopian farmers constitutes only 10 percent of the arable land irrigated by developing countries as a group. The proportion of irrigated arable land in the four neighboring countries was more than 11 times the proportion irrigated in Ethiopia; in particular, the level of irrigation in Egypt was 45 times more than the one in Ethiopia. Irrigation levels in Ethiopia is close to the one in sub Saharan Africa and the poorest five countries, four of which are located in the Equatorial Rainy Forest region.[1] This low

[1] Although FAOSTAT provides the option to download current data on irrigated agricultural area, repeated attempts to download these data in the months of August and September of 2008 produced “no data” response. Moreover, WDI 2007 has no data on this variable for all of these countries on the years later than 2003.

level of use of irrigation is at the face of the persistent drought that mostly changes to famine, making the country an exemplary of the word famine in most common dictionaries.

Low intensity of use of modern inputs results in low crop yields and low production per worker. Ethiopian yield levels of various crops are almost half the yield levels in the four neighboring countries (Table 3.6). Average cereal yield in Ethiopia was about 45 percent of the average yield in developing, low-income food deficit, and the 4 neighboring countries, and it was only 17 percent of the yield in Egypt. I include comparisons of yield levels in Ethiopia with that of Egypt to indicate that with sufficient use of the modern inputs and properly managed soil such yield levels can be achieved even in a desert. As can be seen from row 24, Egyptian yield levels are at least three fold than the ones in Ethiopia for almost all crops.

Taking the average production for the years 1999 to 2001 as a base, Ethiopian average production indices of 1993 to 2004 were inferior relative to similar indices of comparable groups of countries. Production indices are calculated by taking the country's production at a given period as a base. Relatively lower yield levels added with lower production indices imply that a country is not only producing smaller amounts but also it is unlikely to catch up with those regions under the existing conditions. Considering average production in 1999 through 2001 as a base, average per capita agricultural production index decreased by 1.2 percent during the 2002-2004 period while the per capita production index for cereals declined by 4 percent during the same period. The per capita index for food production decreased by 1 percent and non-food crop production per capita index declined by 8.5 percent. The low per capita production indices are the results of the existing low yields coupled with the relatively high growth in population. Declining per capita production indices lead to declining consumption per capita from domestic production, which in turn leads to increasing food deficits. Food aid for Ethiopia has varied in amount but has in general been increasing over the years (Figure 3.2). Cereal aid grew by an average annual rate of 42 percent during the 1993 through

Table 3.6 Comparison of yield levels of Ethiopian farmers with other groups of countries

Groups of countries	Average 2000-2005 Yield, KG/Ha								
	Cereals	Coarse Grain	Pulses	Maize	Wheat	Sorghum	Barley	Roots and Tubers	Coffee
Low-Income Countries	2041	1034	574	1530	2525	812	1470	9023	693
Africa	1268	1081	499	1639	2101	863	960	8260	465
Africa Developing	1191	992	496	1449	2058	853	935	8205	465
Africa South of Sahara	983	907	470	1221	1633	820	1161	8037	465
Asia Developing	3305	2641	750	3841	2846	995	1860	17065	848
Developing Countries	2830	2059	679	3046	2747	1109	1625	12175	728
Low-Income Food Deficit	2785	1812	647	2933	2957	896	1376	11821	549
Average yield by poorest five	1192	1112	647	1135	1005	961	1407	8162	733
Growth rate of yield in poorest five	-0.008	-0.015	0.005	-0.013	-0.011	-0.004	0.005	0.008	-0.030
Average yield by neighbors	2752	2662	1416	2925	3198	2139	1944	10856	516
Growth rate of yield of neighbors	0.005	0.007	-0.004	0.006	0.023	0.005	0.110	0.018	-0.001
Ethiopia	1241	1221	864	1835	1349	1282	1139	7675	913
Average growth rate of yield, Ethiopia	0.024	0.021	0.004	0.039	0.036	0.028	0.038	0.007	0.002
Ethiopia/Developing countries	0.44	0.59	1.27	0.60	0.49	1.16	0.70	0.63	1.25
Ethiopia/ Low income Countries	0.61	1.18	1.50	1.20	0.53	1.58	0.77	0.85	1.32
Ethiopia/SSA	1.26	1.35	1.84	1.50	0.83	1.56	0.98	0.95	1.96
Ethiopia/poorest five	1.04	1.10	1.34	1.62	1.34	1.33	0.81	0.94	1.24
Ethiopia/Neighbors	0.45	0.46	0.61	0.63	0.42	0.60	0.59	0.71	1.77
Ethiopia/Egypt	0.17	0.17	0.29	0.24	0.21	0.22	0.39	0.31	NA
Ethiopia/Africa	0.98	1.13	1.73	1.12	0.64	1.49	1.19	0.93	1.96
Ethiopia/Africa Developing	1.04	1.23	1.74	1.27	0.66	1.50	1.22	0.94	1.96
Ethiopia/ LIFDCs[a]	0.45	0.67	1.34	0.63	0.46	1.43	0.83	0.65	1.66

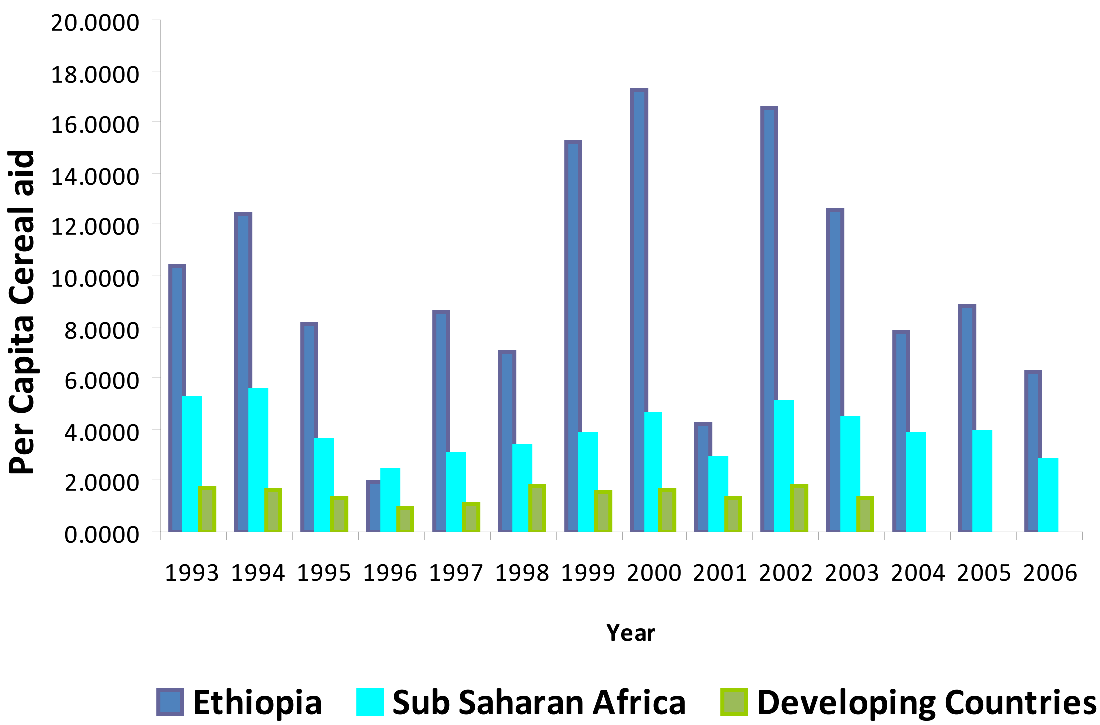
Source: FAO (2006).

Notes: a. LIFDCs stands for Low income food deficit countries.

NA. Stands for data not available.

2006 period, and non-cereal food aid increased by an average annual rate of 35 percent in the same period. Compared with developing countries as a group Ethiopians on average received 7.5 times more cereal aid per head during 1993 to 2003 while this per capita aid was 2.5 times more than the amount received by both the poorest five and Sub-Saharan Africa countries.

Figure 3.2 Per capita cereal aid



Source: FAO (2006).

In January 2005 the FAO indicated that Ethiopia was enjoying a bumper harvest from the main 2004 season caused by timely rainfall, increased use of fertilizer and improved seeds (FAO 2005). Accordingly, 2004's harvest levels were estimated to be about 21 percent above the previous five-year average. However, FAO also estimated that 2.2 million Ethiopians needed emergency assistance and 5.5 million additional people suffered from chronic hunger in 2005, even with the bumper harvest and in a year that is characterized as one of the best recently. This is emblematic of a bleak situation that is continuing to deteriorate.

One can speculate, what would happen to production in Ethiopia, if it were to realize yield levels achieved in the groups I compared it with. Putting aside for now the general equilibrium effects of raising input use to levels observed in other similar areas, the numbers are astounding. If the 2006/7 agricultural season Ethiopian cereal yield levels of 1,520 Kg/ha were to be raised to 2000-2002 world average yield of 3,087 kg/ha or to Egyptian yield level of 7,271 kg/ha the total cereal production could have been about 2 or 4.8 folds of what Ethiopians have actually produced, respectively. The difference in total production between the counterfactual and actual levels would have amounted to about 26 or 97 folds of the cereal donations Ethiopia received worldwide in the same year, respectively.[25] A similar comparison for wheat production shows that 2.2, 1.5 and 5 fold of wheat could have been produced using the world, African, and Egyptian yield levels, respectively. This difference in counterfactual and actual wheat productions could have amounted to 6.6, 3.3 and 22.2 folds of the wheat and wheat flour donations the country received in 2001, respectively.[26]

3.4 An Overview of Agroecologic Zone Production, Cultivated Area, and Yield.

Village level studies conducted on the 15 peasant associations that were included in all 5 rounds of ERHSs accompanied the official data released by International Food Policy Research Institute.[27] In addition to some detailed information on climatic features, history, population size, density, and composition of each peasant association, the studies list the woredas and administrative zones that comprise the peasant associations. I used these studies together with CSA publications to trace the administrative zones and regions that encompass the peasant associations (Table 3.7).[28] The purpose of creating

[25] The counterfactual production was calculated by multiplying the total area devoted for the respective output in Ethiopia by yield levels in the respective countries/groups of countries.
[26] This last comparison is made using 2001 Ethiopian yield, area, and aid levels.
[27] Recall that there were 3 more peasant associations included in ERHS round 5, which were not included in the village level studies.
[28] These administrative zones were designated during the formation of the current federal government in Ethiopia in 1993. Except in 2002 and 2003, CSA published aggregate, administrative region, and administrative zone level annual agricultural production, cultivated area, and yield data starting from 1996 with varying details. Those publications released from 2004 onwards contain the most detailed information. I will be using the series released from 1998 onwards. In the two publications released prior to 1998

such a link is to study the evolution of agricultural production in the 5 agroecologic regions used in the analysis section of this study using data from CSA annual publications released between 1998 and 2008.[29] The objective of this section is to serve as a bridge between the aggregate level descriptive analyses provided in section 3.2 with the household level analysis provided in section 3.5.

Because agroecologic zones do not necessarily overlap with administrative zones that comprise the peasant associations I made some modifications to get to the final list of administrative zones used in the analysis (Table 3.7, column 4). The Eastern Shewa administrative zone comprises both Turufe Ketchema peasant association from Central Highlands and Sirbana Godeti from Arussi/Bale agroecologic zones, I decided to allocate Eastern Shewa administrative zone for Central Highlands and add the Bale administrative zone in the category of Arussi/Bale agroecologic zone. I also included data from the Western Hararghe administrative zone to that of Eastern Hararghe administrative zone while aggregating the data for Hararghe agroecologic zone because only one peasant association is representing this fairly large agroecologic zone. In the following two sections I will describe cultivated area, output, and yield trends in the agroecologic zones first by emphasizing on the relative importance of each agroecologic zone towards countrywide output, area, and yield levels of total agricultural, grains, cereals, and pulses production and then taking a close look at the evolution of the sector in each of the agroecologic zones.

3.4.1 Production, Cultivated Area, and Yield Trends: Major Crops

Cultivated Area

On average, Ethiopian farmers cultivated 9.4 million hectares of land between 1998 and 2007. Total cultivated area expanded in Ethiopia at an average annual growth rate of 7.2

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administrative zone level data were aggregated for two or more administrative zones, making it impossible to separate the data for the administrative zones of interest from others'.

[29] By selecting those administrative zones that encompass the peasant associations included in ERHSs I am essentially forming sample agroecologic zones to represent the agroecologic zones that actually comprise more administrative zones.

Table 3.7 Woredas, administrative zones, and regions of peasant associations included in ERHS

Peasant Association	Woreda	Administrative Zone	Administrative zones used in analysis	Administrative Region	Agroecological zones
Geblen	Subhasaesie	Eastern Tigray	Eastern Tigray	Tigray	Northern Highlands
Haresaw	Atsbi	Eastern Tigray		Tigray	
Shumsheha	Bugna	North Wollo	North Wollo	Amhara	
Dinki	Ankober	North Shewa	North Shewa	Amhara	Central Highlands
Yetmen	Enemay	East Gojjam	East Gojjam	Amhara	
Debre Birhan	Basso and Worana	North Shewa		Amhara	
Turufe Ketchema	Shashemene	Eastern Shewa	Eastern Shewa	Oromia	
Koro Degaga	Dodota	Arussi zone	Arussi zone	Oromia	Arussi/Bale
Sirbana Godeti	Ada'a	East Shewa		Oromia	
			Bale Zone	Oromia	
Adele Keke	Kersa	East Hararghe	East Hararghe	Oromia	Hararghe
			West Hararghe	Oromia	
Imdibir	Chaha	Gurage	Gurage	SNNP	Enset
Aze Deboa	Kedida Gamela	Kembata, Alaba and Timbaro	Kembata, Alaba and Timbaro	SNNP	
Gara godo	Bolosso	North Omo	North Omo	SNNP	
Adado	Adado	Gedeo	Gedeo	SNNP	
Do'oma	Dera-Malo	North Omo	North Omo	SNNP	

Source: ERHS (2004).

percent during the same period. The largest area expansion of 15 percent occurred between 1999 and 2000, but total cultivated area shrunk by an average annual rate of about 2 percent between 2000 and 2003. The Arussi/Bale agroecologic region had the fastest area expansion at an average annual rate of 13.4 percent followed by Central highlands and Northern Highlands at an average annual rate of about 13 percent. The densely populated Enset agroecologic region had the slowest average annual expansion rate of 4.9 percent.

Averaged over the years 1998 through 2007 the agroecological zones spanned by spanned by the survey households as a group accounted for 34 percent of the total

Table 3.8 Cultivated area (1,000 hectares), total agricultural production (1,000 metric tones), and yield (KG/Hectare) in Ethiopia and in agroecologic zones that comprise peasant associations In ERHS

		Year								
Region	Variable	1997	1998	1999	2000	2003	2004	2005	2006	2007
Ethiopia	Area[a]	6,850	8,016	8,217	9,445	8,910	10,108	10,503	10,928	11,321
	Output[b]	7,363	8,584	8,891	10,616	12,350	14,217	15,598	17,170	18,582
	Yield[c]	1,075	1,071	1,082	1,124	1,386	1,407	1,485	1,571	1,641
Northern Highlands	Area[a]	209	269	275	316	272	394	421	436	465
	Output[b]	181	281	247	309	338	752	817	771	1,034
	Yield[c]	865	1,044	896	978	1,242	1,908	1,939	1,766	2,223
Central Highlands	Area[a]	960	1,086	1,214	1,352	773	1,307	1,456	1,405	1,501
	Output[b]	1,080	1,301	1,343	1,531	1,064	1,836	2,364	2,376	2,296
	Yield[c]	1,125	1,198	1,106	1,132	1,376	1,405	1,623	1,691	1,530
Arussi/ Bale	Area[a]	789	882	884	911	518	1,249	1,015	859	858
	Output[b]	1,113	1,025	1,064	1,239	849	2,039	1,593	1,353	1,433
	Yield[c]	1,410	1,163	1,203	1,360	1,638	1,633	1,570	1,575	1,670
Hararghe	Area[a]	251	309	338	418	426	394	493	485	501
	Output[b]	330	431	498	617	579	673	756	888	1,279
	Yield[c]	1,314	1,397	1,475	1,476	1,357	1,709	1,534	1,830	2,555
Enset	Area[a]	313	418	407	597	324	206	208	207	233
	Output[b]	381	440	451	709	495	384	387	395	461
	Yield[c]	1,216	1,053	1,108	1,187	1,529	1,861	1,858	1,909	1,977

Source: CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008)

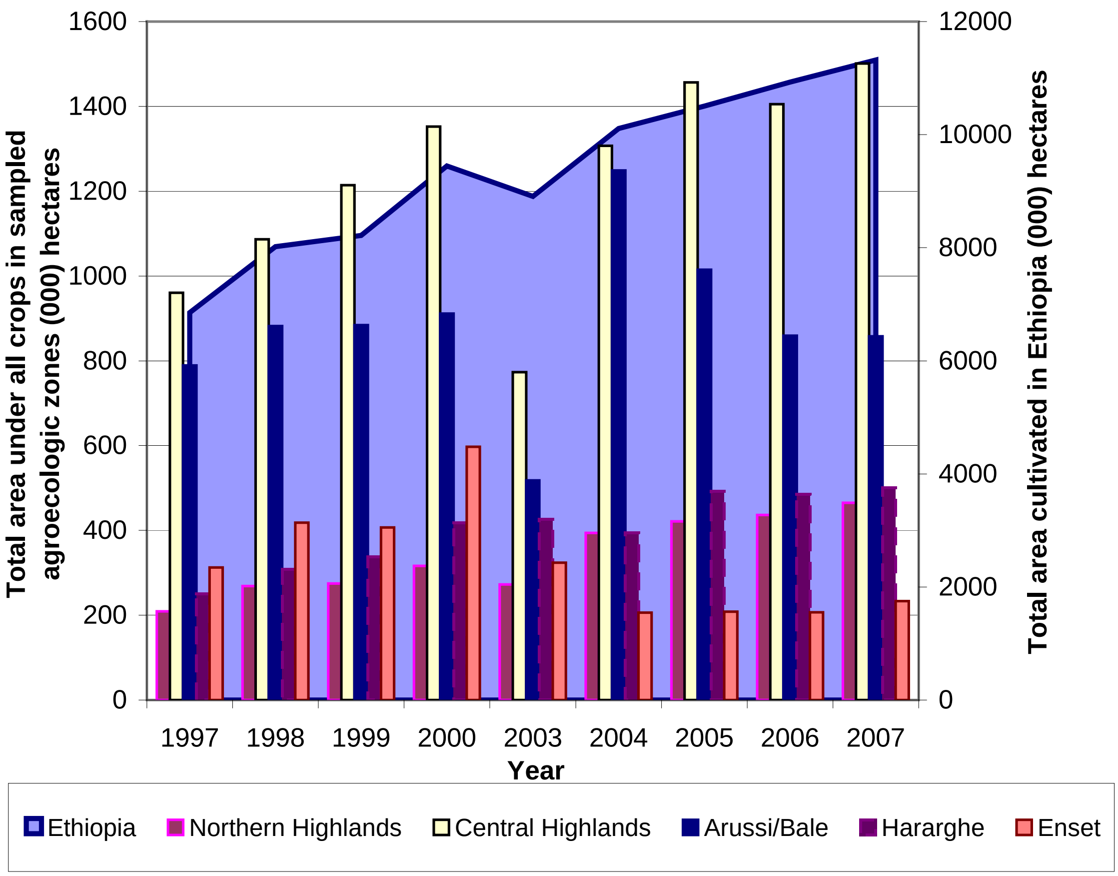
Note: a. Area is in 1,000 hectares.

b. Output is in 1,000 metric tones. Output data for 2004 onwards is the sum of grains, Vegetables, root crops, fruit crops, and stimulants

c. Yield is given in kilograms per hectare

cultivated area in the country, on average each agroecologic zone accounted for 7.8 percent of the total cultivated area. The largest value accounted for by these agroecologic zones occurred in 2000, with a value of 38 percent, the smallest in 2003, with a value of 26 percent. This low value is the result of a significant decline in cultivated area in Central Highlands, Arussi/Bale, and Enset agroecologic zones between 2000 and 2003 (Figure 3.3). Assuming the sampled administrative zones as fair representatives of the agroecologic zone structure of Ethiopia [and calculating the proportion accounted for by each agroecologic zone to total cultivated areas within this group], Central Highlands is the largest, accounting for 38 percent of total cultivated area on average during 1997-2007. On average, the Arussi/Bale agroecologic zone accounted for about 29 percent, Hararghe accounted for about 13 percent, and the Enset and Northern Highlands agroecologic zones each accounted for about 10.5 percent of the total area cultivated nationwide.

Figure 3.3 Trends in total cultivated area in Ethiopia and in the five agroecologic zones



Source: CSA (1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, and 2008)

Grain production, which includes cereals, pulses, and oilseeds, accounted for the largest proportion of total cultivated area. During the 1998-2007 period, on average about 9 million out of the 9.4 million hectares of total cultivated area was sown to grains. That is, on average about 96 percent of the total cultivated area was used for grain production. This average did not vary much throughout the period. The smallest proportion of agricultural land devoted for grains production during this period was 94 percent, which happened in 1997. Since the area under grains represented the majority of agricultural area during this period, changes in total cultivated area was a reflection of what was happening in grains production. Agricultural land that was sown to grains grew by an average annual rate of 7.3 percent, close to the 7.2 percent annual growth rate of total cultivated area. In general, the qualitative aspects of total cultivated land, the importance of area sown to grains in the sampled administrative zones towards aggregate cultivated area, and the comparisons made between the agroecologic zones does not change when considering cultivated area under grains. In fact, many of the proportions stay put.

On average 7.4 million hectares of agricultural land was sown to cereals in Ethiopia between 1997 and 2007. This ranged from 5.6 million hectares in 1997 to 8.5 million hectares in 2007. Cereals, by far the single most important crop category, accounted for an average of 79 percent of the total cultivated area during the 1997-2007 period. On average, the area sawn to pulses accounted for about 12.5 percent of the total cultivated area, while the remaining 8.5 percent of the area was allocated for oilseeds, vegetables, root crops, fruits, and stimulants.[30] The area sown to cereals was at least 76 percent of the total cultivated area. The average numbers for the period between 1997 and 2007 confirm the same conclusion made earlier about the importance of individual crop items. On average, teff, the single most important crop, was sown to 23 percent of the total agricultural area, and the five most important crops: teff, maize, sorghum, wheat, and barley accounted for at least 72 percent of the total cultivated area during the 1997-2007 period. On average, they accounted for about 75 percent of the total cultivated area in the country or they accounted for 94 percent of the area under cereals during the period.

[30] I have not gone into the specific details of other categories for two reasons: most of the CSA publications used in this section do not include these categories and even when they do most of the entries are “not available”. Second, the importance of these crops as a group, calculated as a remainder out of total agricultural activity, is less than any of the crops included in the cereals category, which I decided to concentrate on.

The area sown to cereals increased by an average annual growth rate of 6.7 percent. In other words, out of the 4.4 million hectares of absolute difference in total cultivated area between the beginning of the period, 1997, and the end of the period, 2007, 70 percent was the result of an increase in the area that is sawn to cereals. The fastest expansion of the area under cereals of 9 percent occurred between 2003 and 2004 while the area sawn to cereals declined between 2000 and 2003 by an average annual rate of 3 percent. During the 1997-2007 period the area allocated for cereals production has increased the fastest in the Hararghe agroecological zone, which grew at an average annual rate of 9.7 percent, followed by the Enset agroecologic zone at 8.8 percent. The Arussi/Bale agroecologic zone had the slowest average annual growth rate of 3.5 percent.

Considering the sampled agroecologic zones as fair representatives of the agroecologic zone structure in the country, Central Highlands accounted for 39 percent of the area under cereals, Arussi/Bale for 29 percent, Hararghe for 13 percent, Enset for 10 percent, and Northern Highlands accounted for 9 percent of the area under cereals. The average annual growth rate of the area under cereals in the sampled agroecologic zones was 7.1 percent, a little higher than the nationwide growth rate of 6.7 percent. In these agroecologic zones the area allocated for cereals grew fast between 1997 and 1998, at 26 percent, but it decreased by an average annual rate of 7 percent between 2000 and 2003.

On average 1.1 million hectares of cultivated land was sown to pulses between 1997 and 2007. Pulses are not only the second most important crop category in terms of absolute area but also the area sown to pulses is growing relatively faster, with an average annual growth rate of 9.2 percent. On average, the area under pulses was growing 97 percent faster than the growth in total agricultural area. Central Highlands accounted for the largest cultivated area under pulses, followed by Arussi/Bale agroecologic zone. The Hararghe agroecologic zone is the least important in terms of the area that is sown to pulses.

Agricultural Production

Total annual agricultural production averaged about 12.6 million metric tons between 1997 and 2007. Total output increased by an average annual growth rate of 11 percent, implying an increase in average total agricultural yield during the period given that cultivated area increased only by an annual average growth rate of 7.2 percent. The largest growth in output of 20 percent was attained between 1999 and 2000 while output has grown only by 3.6 percent between 1998 and 1999.

Between 1997 and 2007 Northern Highlands agroecologic zone had the fastest average annual growth rate in output of 29 percent. Although this agroecologic zone was ranked third in average annual growth rate of cultivated area, its average annual growth rate of output was almost 10 percent faster than the growth rate in the second fastest growing Hararghe agroecologic zone. In particular, the Northern Highlands agroecologic zone achieved the largest growth rate in total agricultural production of 122 percent between 2003 and 2004, during which period total cultivated area expanded only by 45 percent.

The proportion of total agricultural output accounted for by each of the agroecological zones closely resembles their share of total agricultural area, although their share of total output is slightly higher at an average annual contribution rate of 38 percent. The agroecological zones that accounted for the largest and smallest share of total cultivated area, Central Highlands and Northern Highlands agroecologic zones, respectively, accounted for the largest and smallest shares of total agricultural output.

Total grains production averaged 11.3 million metric tones between 1997 and 2007. Grains production increased throughout of the period, except between 2000 and 2003 when total grains output essentially remained constant. On average, grains production increased by an average annual growth rate of 11 percent. Just as in the case of total cultivated land, grains represent a large proportion of total agricultural output. On average, grains accounted for about 91 percent of total agricultural production during the 1998-2007 period. This is lower relative to the average total area devoted for grains production, 96 percent.[31] Because a significantly large proportion of the total agricultural production of the five agroecologic zones is accounted for by grains, the importance of each agroecologic zone in total grains production as well as the relative importance of this sub-sector within the group of the agroecologic zones did not change from what was discussed for total agricultural production.

During the 1997-2007 period an average of 9.8 million metric tones of cereals were produced annually. Cereals production increased during the period at average annual rate of 10 percent, except in 2000 through 2003, during which period it declined by an average annual rate of 1 percent. Cereals production accounted for the largest proportion of total agricultural output and grains production. On average, cereals production accounted for about 80 percent total agricultural production and for 88 percent of grains production. The Northern highlands agroecologic zone had the fastest growing cereals production sub-sector at an average annual growth rate of 24 percent while cereals production grew slowest by an average annual rate of 2.3 percent in the Enset agroecologic zone. The rankings of the importance of agroecologic zones production towards total agricultural production did not change: the sampled agroecologic zones accounted for 36 percent of nationwide cereals production, and on average, Central Highlands and Northern Highlands accounted for the largest and smallest proportion towards total cereals production in the country.

On average, 1.2 million metric tones of pulses were produced between 1997 and 2007 annually. Pulses production grew by an average annual rate of 14 percent during the period, faster than the annual growth rate of cereals or total agricultural production, and notwithstanding an average annual decline of 1 percent during the 2000-2003 and a 6 percent decline during the 2004-2005 periods. Pulses production accounted for 12.5 percent of total agricultural production and for 13 percent of grains production. Similar to

[31] There is a peculiar feature in grains data: the average share of grains production out of total agricultural production for the period of 1998-2000 is 98 percent while the one between 2003 and 2007 is 85 percent. Recall that total agricultural output for the years 2004 onwards was the sum of grains, vegetables, root crops, fruit crops, and stimulants while during the 1997-2000 period, grains data was the sum of only cereals and pulses (data for oilseeds, among others, was not available). The first aggregation should have no effect on the share of grains while the second should have led to a lower share of grains out of total agricultural production in the 1997-2000 period, not otherwise.

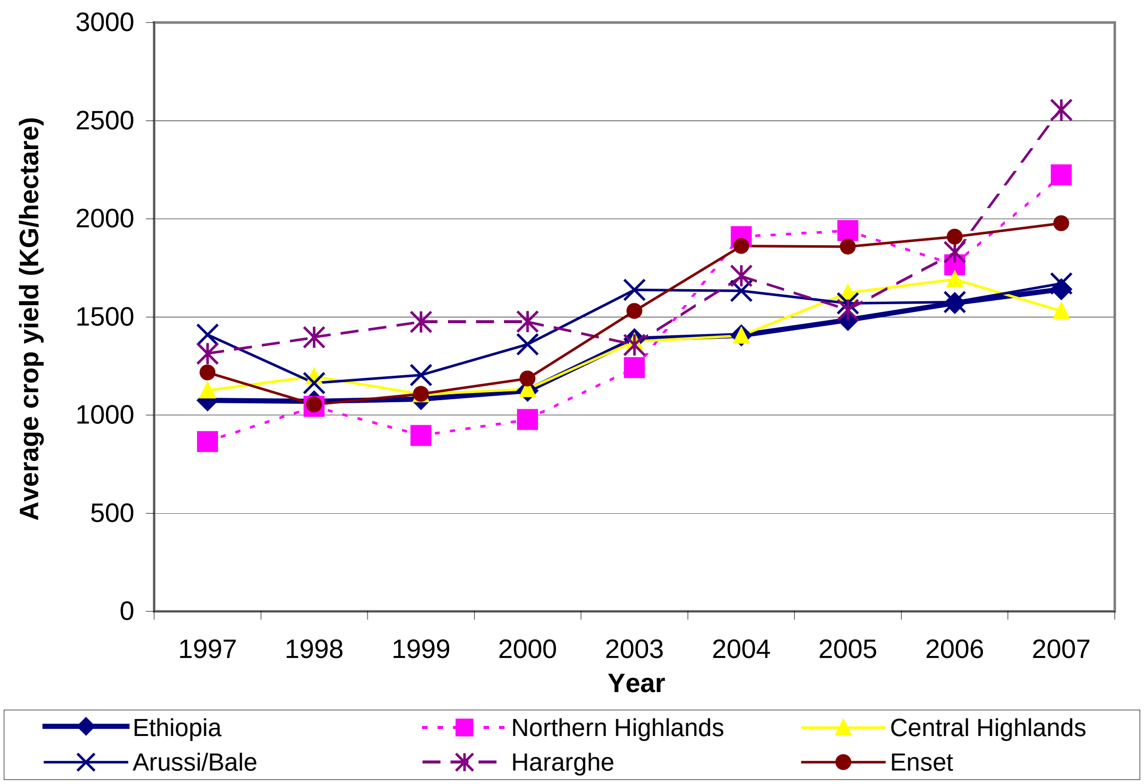
their contribution towards total agricultural and grains production, the sampled agroecologic zones accounted for an average of 38 percent of the total pulses produced nationwide between 1997 and 2007. Northern Highlands, which had the smallest contribution for total agricultural, grains, and cereals production, ranked third in its contribution for pulses production after Central Highlands and the Arussi/Bale agroecologic zones, the Enset agroecologic zone contributed the least for pulses production.

Agricultural Yield

Total agricultural yield averaged 1,316 KGs/hectare in Ethiopia during the 1997-2007 period. Average yield steadily increased during the period with an average annual growth rate of 4 percent, roughly the difference between average annual growth rates of total agricultural production and total cultivated land. The annual growth rate of total agricultural yield ranged from 8 percent between 2000 and 2003 to a slight decline in yield between 1997 and 1998. Average annual yield declined only during 1997-1998, by about 4 kilograms per hectare. During the entire period, annual yields levels of each of the sampled agroecologic zones were either equal to, almost equal to, or mostly greater than the aggregate annual yield levels, except in Northern Highlands between 1998 and 2003. Average annual yield levels in the agroecologic zones ranged between 1,627 KGs/hectare in the Hararghe agroecologic zone, which is 24 percent higher than the countrywide average, to 1,354 in Central highlands.

At an average annual growth rate of 12 percent, Northern highlands had the fastest growth rate in total agricultural yield while the Arussi/Bale agroecologic zone had the slowest growth rate of 1 percent. On average, the agroecologic zones had an annual growth rate in yield of 6 percent, 2 percent higher than the countrywide growth rate. Within the agroecologic zones in the sample the largest annual growth rate in yield of 21 percent was registered between 2003 and 2004 while annual yield levels declined between 1998 and 1999. I compared the performance in terms yield of each of the agroecologic zone relative to the average yield level of the zones in this sample. Relative to the average annual yield levels of the agroecologic zones, Central Highlands performed the poorest producing only 92 percent of the average yield in the five agroecologic zones while the Hararghe agroecologic zone performed superior, at an average yield level that is 11 percent higher than the agroecologic average yield levels.

Figure 3.4 Total agricultural yields in KG/hectare in Ethiopia and in the five agroecologic zones during the 1998-2007 period



Source: Data from CSA (1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, and 2008).

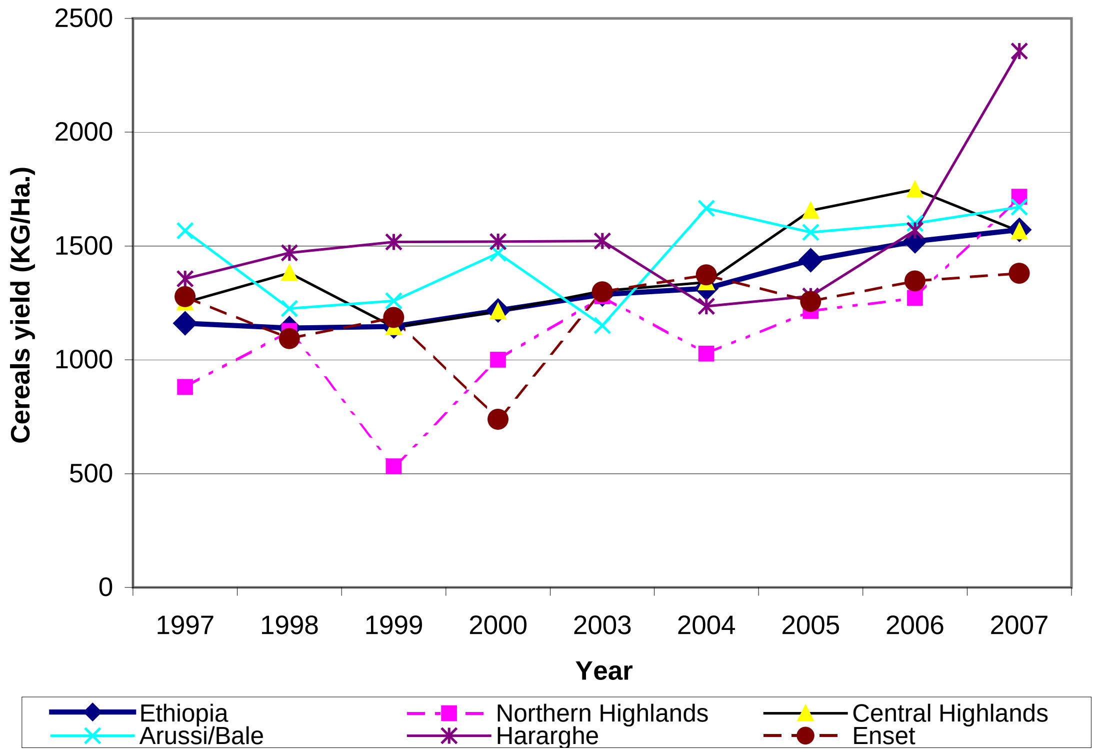
Average annual grain yield levels were 1235 KG/hectare during the 1998-2007 period, lower than the average total agricultural yield level of 1315 KG/ha. Specifically, grain yield levels during the 2003-2007 period were smaller than the total agricultural yield levels while they were larger during the 1997-2000 period [recall that the proportion of grains out of total agricultural production declined from 98 percent during the 1997-2000 period to 85 percent during the 2003-2007 period]. At 3.4 percent, the average annual growth rate of grain yield was slightly lower than the average annual growth rate of total agricultural yield. The fastest growth in grain yield of 8.4 percent was recorded between 2003 and 2004. Grain yield declined during the period in which total agricultural yield declined, 1997-98.

Unlike the case of total agricultural yield levels where on average all agroecologic zones performed better than the aggregate yield levels, on average, the Northern Highlands and the enset agroecological zones performed poor relative to aggregate grain yield levels by producing only 87 and 90 percent of nationwide yield levels, respectively. The Hararghe agroecologic zone outperformed all in grains yields, although not by as much as its performance in total agricultural yield. Even if their performance in terms of average yield levels is lower than the national average, the Northern Highlands and Enset agroecologic zones had the first and third fastest growing yield levels. At only 2.2 percent, average grain yield levels grew slowest in Arussi/Bale agroecologic zone.

Between 1997 and 2007 Ethiopian farmers produced an average of 1310 KGs per hectare of cultivated land that was sown to cereals. Except for the 2 percent decline between 1997 and 1998, cereals yield grew throughout of the period at an average annual growth rate of 3.4 percent. Cereals production grew in the sampled agroecologic zones by a higher average annual rate of 5.6 percent. The Northern Highlands agroecologic zone, which had the poorest performance in terms of relative yield levels by producing an average yield of 84 percent of nationwide yield levels, had the fastest growth in yield levels of about 14 percent. The Enset agroecologic zone not only performed poor relative to nationwide yield levels but it had an average annual decline in cereals yield of 1.4 percent. The agroecologic zone with the second fastest growing yield levels, the Hararghe agroecologic zone, had an average cereals yield level that was 18 percent higher than the national average.

During the 1997-2007 period average pulses yield levels were 965 KGs per hectare. The only agroecologic zone that performed worse than the national average in pulses yields was the Enset growing agroecologic zone, producing on average 891 KGs/hectare. On

Figure 3.5 Total cereals yields in kg/hectare in Ethiopia and in the five agroecologic zones during the 1998-2007 period



Source: Data from CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008)

average, pulses yield of the sampled agroecologic zones was 11 percent higher than produced nationwide. Yield levels of the Hararghe agroecologic zone were 34 percent higher than the national average. Similar to overall agricultural yield and other crop categories pulses yield levels increased by an average annual growth rate of 4.2 percent. Although the Northern Highlands agroecologic zone performed poor relative to the sample average, it performed a little better than the nation average and had the fastest growth of 9.4 percent in pulses yields during the period.

3.4.2 Production, Cultivated Area, and Yield: Trends in ERHS Agroecologic Zones

The previous section provided time series features of cultivated area, production, and yield levels of major crop categories in Ethiopia as well as the contribution and performance of each of the agroecologic zones relative to nationwide aggregates and between themselves. As a precursor to the analysis I will be conducting in chapter 4, the next section deals with the relative importance of each crop category and item in each agroecologic zone and the evolution of cultivated area and yield levels with in the agroecologic zone during the period between 1997 and 2007. I decided to emphasize on cultivated area and yield as one can recalculate output from these two numbers; however, I will use output when necessary.

Northern Highlands

Eastern Tigray and North Wollo administrative zones constitute the sampled Northern Highlands agroecologic zone (Table 3.7). As we shall see in chapter 4 this region is generally resource poor and the most devastated by the civil war that ended in 1991. At the wake of the establishment of the current government in 1993 such war torn regions were given special attention by a decree, which may have contributed to a relatively fast expansion in cultivated area and a faster growth in yield levels. However, this region performed poor in terms of absolute yield level as it has to catch up with other agroecologic zones.

On average farmers of this agroecologic zone cultivated 0.34 million hectares of land between 1997 and 2007. The total cultivated area increased by an average annual rate of 13 percent to reach the highest level of 0.45 million hectares in 2007 from the lowest level of 0.2 million hectares at the beginning of the period. The area allocated for grains production dominated the total cultivated area of Northern Highlands, on average accounting for 88 percent of the total cultivated area. Out of grains, the cereals sub-category accounted for an average of 70 percent of total cultivated area, while pulses accounted for an average of 16 percent of total cultivated area. The remaining 15 percent of total cultivated area was used for oilseeds, vegetables, root crops, fruit crops, and stimulants production.

Table 3.9 Cultivated area (1,000 hectares) under different crop categories and the proportion of total area accounted for by crop categories and crops in Northern Highlands agroecologic zone between 1997 and 2007

Crop type	1997	1998	1999	2000	2003	2004	2005	2006	2007	Average
	In thousands of hectares									
Total cultivated area	209	269	275	316	272	394	421	436	465	340
Area under grains	203	261	268	308	272	298	301	340	344	288
Area under cereals	163	220	216	241	221	231	245	268	267	230
Area under pulses	39	41	52	67	46	59	49	62	70	54
Area under 5 major cereals[a]	152	213	191	236	214	227	237	259	259	221
	Proportions of total area sown to crop category/crop									
Proportion under grains[b]	0.97	0.97	0.97	0.98	1.00	0.76	0.71	0.78	0.74	0.88
Proportion under cereals[b]	0.78	0.82	0.79	0.76	0.81	0.59	0.58	0.62	0.57	0.70
Proportion under pulses[b]	0.19	0.15	0.19	0.21	0.17	0.15	0.12	0.14	0.15	0.16
Proportion under 5 major crops[b]	0.73	0.79	0.69	0.75	0.78	0.58	0.56	0.59	0.56	0.67
Proportion under teff[b]	0.21	0.22	0.24	0.20	0.27	0.18	0.16	0.17	0.15	0.20
Proportion under barley[b]	0.19	0.20	0.20	0.19	0.19	0.16	0.12	0.15	0.15	0.17
Proportion under wheat[b]	0.19	0.18	0.12	0.18	0.13	0.11	0.10	0.11	0.14	0.14
Proportion under maize[b]	0.05	0.07	0.04	0.03	0.03	0.02	0.03	0.03	0.02	0.03
Proportion under sorghum[b]	0.12	0.12	0.09	0.15	0.17	0.10	0.15	0.14	0.09	0.12

Source: Data from CSA (1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, and 2008).

Notes: a. The 5 major cereals are teff, barley, wheat, maize, and barley.

b. The proportions are calculated out of total cultivated area.

The five most important crop items of teff, barley, wheat, maize, and sorghum accounted for an average of 67 percent of the area that is annually cultivated in Northern Highlands. While these crops are still significantly important as a group and individually, their relative importance has declined in recent years. Specifically, during the 1997-2003 period these five crops accounted for 75 percent of total cultivated area while during the 2004-2007 period the area under these crops accounted for only 57 percent of the total cultivated area. However, the absolute area under these crops grew throughout the period. The cultivated area under these five cereals increased by an average annual growth rate of 9 percent during the 1997-2003 period and by an average annual growth rate of 5 percent during 2004-2007. That is, most of the 13 percent of average annual increase in total cultivated area during 2004-2007 was used for increased production of other items than the 5 major crops.[32]

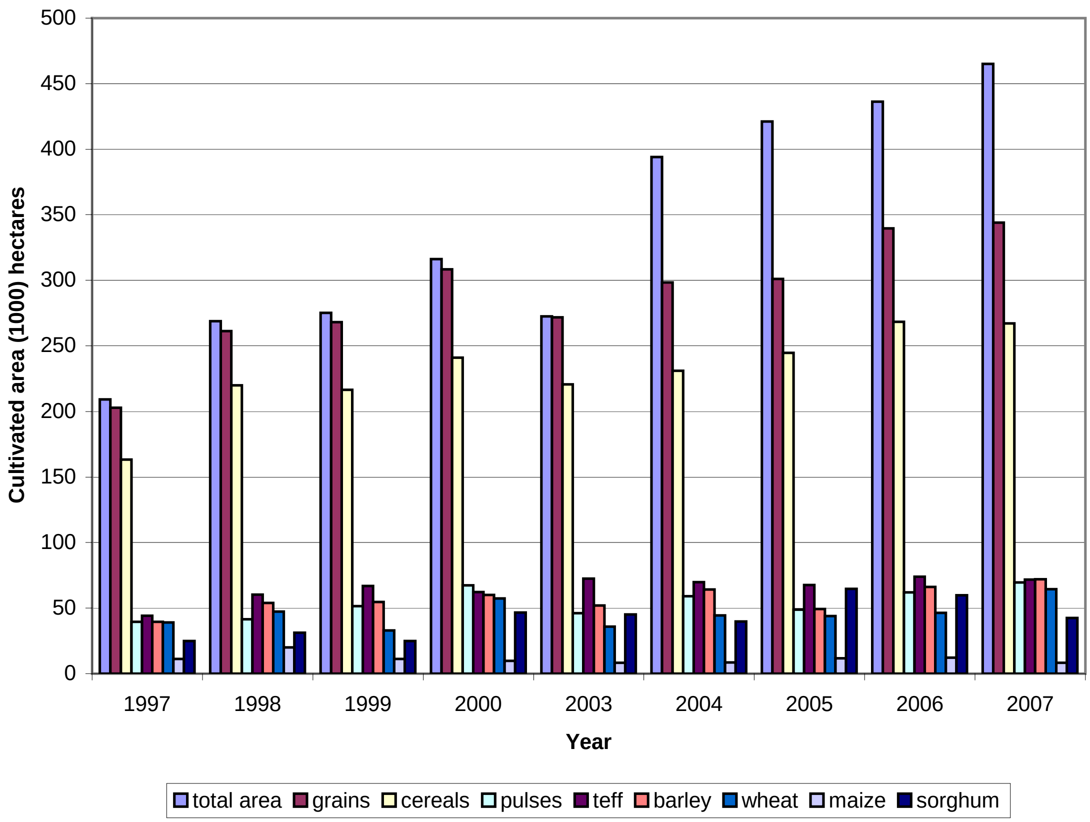
Teff, whose only use is to make the traditional bread called “enjera”, is a staple crop in almost all of Ethiopia and predominantly so in the northern half of the country. One-fifth of the total agricultural area cultivated in Northern Highlands agroecologic zone was used to grow this single most important crop. Even if the area allocated for teff production has increased by an average annual rate of 1 percent during 1998-2007 (ignoring the growth rate between 1997 and 1998, when the area under all items grew by 20 percent or more, except the area under pulses) it is losing its importance just as other cereals and pulses as a group. The proportion of cultivated area under grains declined from an average of 98 percent during 1997-2003 to 75 percent during 2004-2007, the proportion of area under pulses declined from an average of 18 to 14 percent, the proportion under barley declined from 19 to 15 percent, that under wheat from 16 to 12 percent, and from 13 to 12 percent in sorghum production. The last three crop items follow teff in the list of most important crops, although wheat and sorghum take turns in taking the third place in different years. Even if the importance of cereals and pulses is declining individually, these categories still comprise such a significant proportion of the total cultivated area that trends in total cultivated area follow the trend these crop categories take.

On average, farmers in Northern Highlands agroecologic zone harvested 1,429 kilograms of output per year per each hectare of land they cultivated between 1997 and 2007. Although this agroecologic zone had relatively fast growing yield levels its performance in terms of absolute yield levels was the worst in almost all individual crops and categories. In particular, this agroecologic zone suffered from low harvests in 1997 and 1999. Average annual growth rates are generally high when considering the period after

[32] This observation feeds into the argument and research direction I noticed in Ethiopia in early 2007 that sprung from the increase in consumer prices that started in 2004 and still climbing. One of the favored arguments for the causes of the inflation was that farmers shifted from producing staple crops and are allocating more land for export items, as a result of which they may have reduced the supply of marketed cereals, which they can now afford to consume that they have another means of income. I did not see any publication confirming this, especially given the severe shortfalls in hard currency that the country is facing now due to relatively low exports.

2000. Total agricultural yield grew by an average annual rate of 15 percent, grains by 17 percent, and cereals by an average annual rate of 23 percent between 2000 and 2007.

Figure 3.6 Trends in cultivated area under different crop categories and crops in Northern Highlands agroecologic zone during 1997-2007



Source: CSA (1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, and 2008).

Average annual growth rate of yield in Northern Highlands was just about the difference between the average annual growth rates of output and area of cultivated land, which was 16 percent. The five important cereals had average yield levels that were larger than the average for cereals as a group, implying that there were other crops with lower yield levels. Cereals yields are on average larger than grains yields, which in turn imply that there are other categories, such as pulses and oilseeds, with lower yield levels. However, notwithstanding the low grains, cereals, and pulses yields, total agricultural yield levels

Table 3.10 Annual yield levels of crop categories and crops in Northern Highlands between 1997 and 2007

Crop type	Year									Average
	1997	1998	1999	2000	2003	2004	2005	2006	2007	
Yield	Kilograms per hectare									
Total agriculture	865	1044	896	978	1242	1908	1939	1766	2223	1429
Grains	827	1106	612	988	1241	1009	1158	1231	1577	1083
Cereals	881	1127	532	1000	1279	1026	1214	1272	1717	1117
Pulses	601	993	948	997	1139	1044	977	1156	1117	997
Average of 5 major cereals	835	941	1008	1105	1305	1013	1265	1310	1403	1132
Teff	632	906	863	762	999	904	843	973	1199	898
Barley	953	1067	984	935	1302	965	1341	1399	616	1062
Wheat	1101	1030	1660	962	1452	1088	1220	1329	1345	1243
Maize[a]	1338	1903	1623	1520	1176	725	1456	1411	1752	1117
Sorghum[b]	151	1270	1289	1349	1597	1385	1468	1436	2101	1338
	Period									
Annual growth rates	97-98	98-99	99-00	00-03	03-04	04-05	05-06	06-07	Average	
Total agriculture	0.207	-0.142	0.091	0.090	0.536	0.016	-0.090	0.259	0.121	
Grains	0.338	-0.446	0.614	0.085	-0.186	0.147	0.063	0.281	0.112	
Cereals	0.280	-0.528	0.878	0.093	-0.198	0.183	0.047	0.350	0.138	
Pulses	0.652	-0.045	0.051	0.047	-0.083	-0.06	0.183	-0.034	0.088	
Average of 5 major cereals	0.127	0.071	0.097	0.060	-0.223	0.249	0.035	0.071	0.061	
Teff	0.434	-0.047	-0.118	0.104	-0.095	-0.07	0.154	0.233	0.075	
Barley	0.120	-0.078	-0.050	0.131	-0.259	0.389	0.044	-0.560	-0.033	
Wheat	-0.06	0.611	-0.420	0.170	-0.251	0.121	0.090	0.012	0.034	
Maize	0.422	-0.147	5.246	-0.075	-0.384	1.009	-0.031	0.242	0.612	
Sorghum	7.394	0.014	0.047	0.061	-0.133	0.060	-0.021	0.462	0.986	

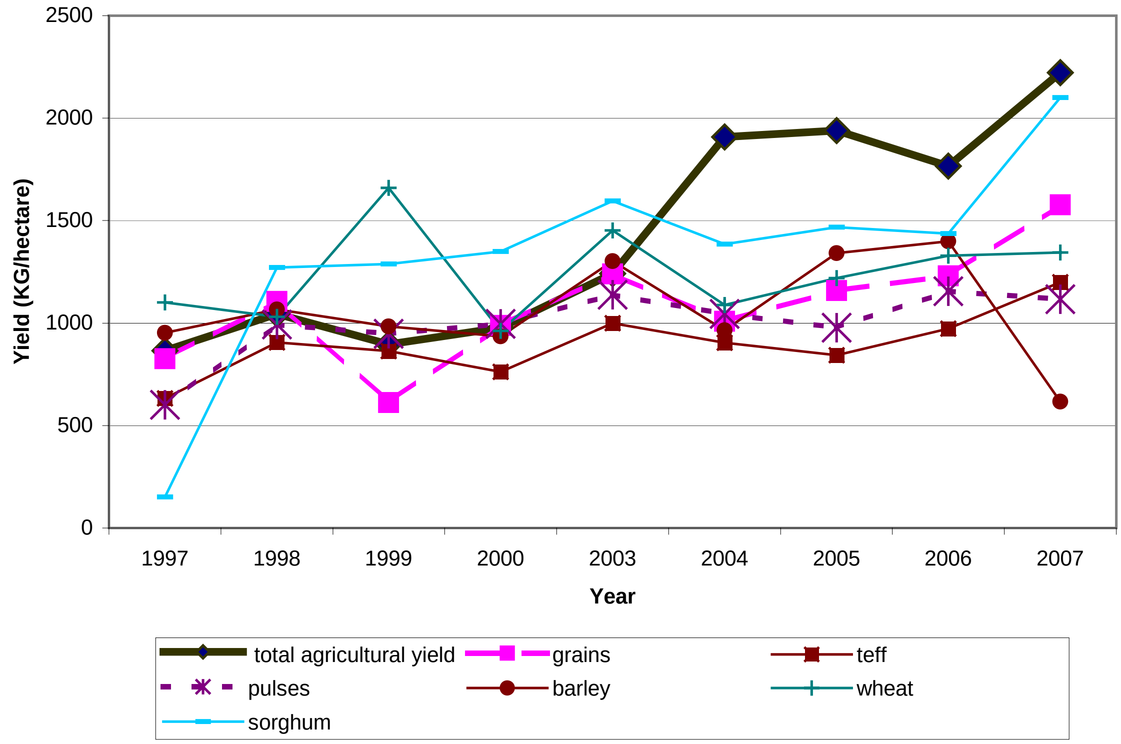
Source: Data from CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

Notes: a. Data available only for East Tigray for 1997, 1998, and 1999.

b. Data available only for East Tigray for 1997.

are at least 300 KGs larger than any crop category in any given year. Moreover, total agricultural yield grew faster than grains, which in turn grew faster than the five major crops and pulses, implying the existence of other crops that are fueling the fast growth in total agricultural yield which are not captured by CSA data.

Figure 3.7 Annual yield levels of crop categories and important crops in Northern Highlands between 1997 and 2007



Source: Data from CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

Central Highlands

The North Shewa and East Gojjam administrative zones from Amhara and Eastern Shewa administrative zone from Oromia administrative region make up the sampled Central Highlands agroecologic zone. This agroecologic zone accounts for the largest proportion of nationwide cultivated area, and output. Seven out of the 18 peasant associations included in ERHS were sampled from this agroecologic zone (Table 2.1). Similarly, the sample administrative zones used in this section on average accounted for 12 percent of total cultivated area, 13 percent of total agricultural output, and on average farmers of this agroecologic zone had 6 percent more yield than the national average.

Grains, cereals, pulses, and the five important crop items remain important in this agroecologic zone except that teff becomes so much important that it accounts for more

Table 3.11 Cultivated area (1,000 hectares) under different crop categories and the proportion of total area accounted for by crop categories and crops in Central Highlands agroecologic zone between 1997 and 2007

Crop type	1997	1998	1999	2000	2003	2004	2005	2006	2007	Average
	In thousands of hectares									
Total cultivated area	960	1086	1214	1352	1252	1307	1456	1405	1501	1281
Area under grains	931	1008	1181	1158	1233	1291	1435	1394	1494	1236
Area under cereals	748	876	924	1065	984	985	1139	1107	1179	1001
Area under pulses	183	132	257	93	213	261	250	243	275	212
Area under 5 major cereals[a]	746	874	809	1064	981	981	1131	1105	1174	985
	Proportions of total area sown to crop category/crop									
Proportion under grains[b]	0.97	0.93	0.97	0.86	0.985	0.99	0.99	0.99	0.995	0.96
Proportion under cereals[b]	0.78	0.81	0.76	0.79	0.79	0.75	0.78	0.79	0.79	0.78
Proportion under pulses[b]	0.19	0.12	0.21	0.07	0.17	0.20	0.17	0.17	0.18	0.17
Proportion under 5 major crops[b]	0.78	0.80	0.67	0.79	0.78	0.75	0.78	0.79	0.78	0.77
Proportion under teff[b]	0.33	0.36	0.34	0.33	0.31	0.31	0.30	0.36	0.34	0.33
Proportion under barley[b]	0.08	0.07	0.07	0.07	0.09	0.09	0.08	0.08	0.07	0.08
Proportion under wheat[b]	0.14	0.15	0.10	0.16	0.15	0.17	0.17	0.18	0.17	0.15
Proportion under maize[b]	0.15	0.14	0.12	0.14	0.13	0.11	0.13	0.09	0.10	0.12
Proportion under sorghum[b]	0.07	0.09	0.04	0.08	0.11	0.08	0.10	0.08	0.10	0.08

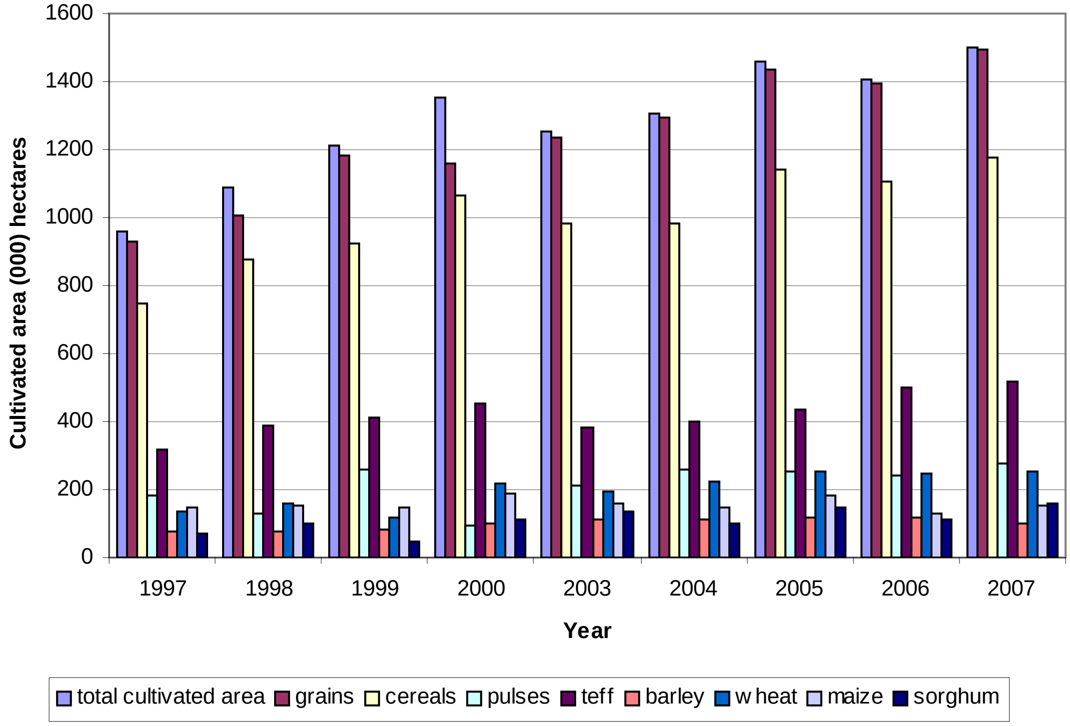
Source: CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

Notes: a. The 5 major cereals are teff, barley, wheat, maize, and barley.

b. The proportions are calculated out of total cultivated area.

than twice the area sown to pulses as a group, taking on average 33 percent of the total cultivated area during 1997-2007 and showing no sign of slowing down. The area allocated for teff has on average grew by 8 percent, expanding on average faster than the area under cereals as a group and under the five major crops, and was a little slower than the growth rate of total cultivated area, which grew at an average annual rate of 10 percent, and the growth rate of grains, which grew at an average annual rate of 9 percent. Considering the category of the 5 major crops, the area under wheat (the second most important crop), barley (the fourth most important crop), and the area under the least important of the 5 in this agroecologic zone, sorghum, all grew faster than the area under teff, but on average the total area under all the three crops accounted for only 94 percent of the area under teff, clearly showing the importance teff has in this large agroecologic zone, and in the country as a whole, given that the same evidence is corroborated with similar observations in other agroecologic zones.

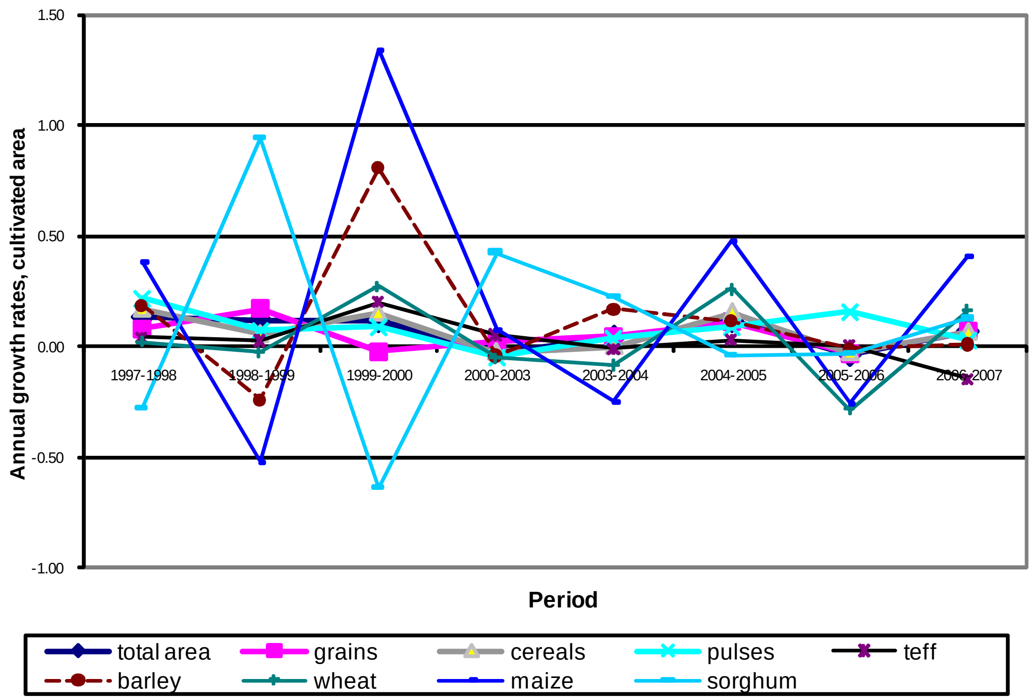
Figure 3.8 Trends in cultivated area under different crop categories and crops in Central Highlands agroecologic zone during 1997-2007



Source: CSA (1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, and 2008).

Unlike in the Northern Highlands agroecologic zone where the importance of cereals and grains was declining, farmers in Central Highlands agroecologic zone on average allocated 96 percent of their land for grains production, this proportion had a variance of only 0.002, and the proportion had actually increased during the 1997-2007 period. The proportion of the area under the 5 important crops out of total cultivated area averaged at 77 percent, showed no sign of declining, and had a variance of less than 0.002. Moreover, these five crops on average accounted for more than 98 percent of the area under cereals out of which teff accounted for 42 percent. Average annual growth rates of the area under the major crop categories and individual crops are so important that the growth rate of total cultivated area followed the same trend that growth rates followed by the important crops, and growth rate of total cultivated area and the area under grains collapse into one for most of the period between 1997 and 2007 (Figure 3.9).

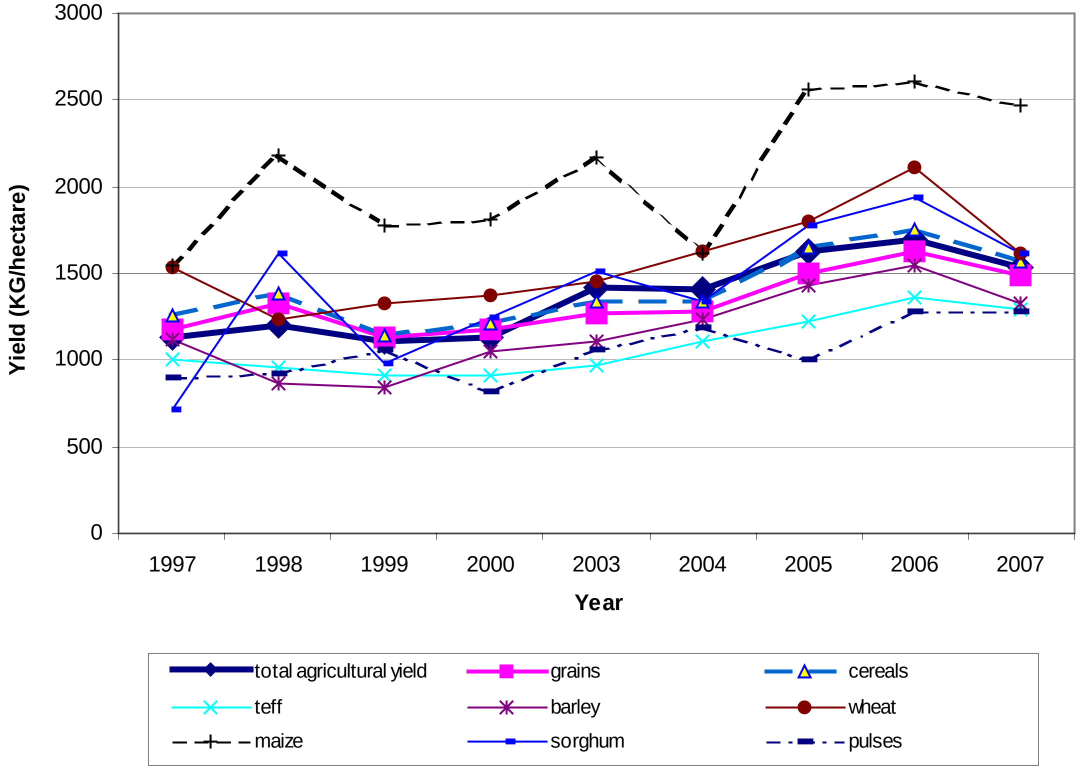
Figure 3.9 Annual growth rates in area of cultivated land under different crops and categories in Central Highlands between 1997 and 2007



Source: Data from CSA (1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, and 2008).

The importance of the area that is allocated for the specific crops discussed above mainly draws from the food culture of the inhabitants, and the market value and the superiority in nutrients (Mengesha 1965) of such crops as teff. However, teff production requires a lot more work than any other crop while average teff yields are a lot less than any other cereal. During the 1997-2007 period annual teff yields in Central Highlands were, on average, 21 percent higher than nationwide teff yield; however, on average teff yield in Central Highlands constituted only 92 percent of its own barley yield levels, a crop that Central Highlands performed worst relative to nationwide average, producing only 88 percent of the national average yield levels. While the superior performance in teff yields justifies its production in this agroecologic zone, it also warrants that poor performing agroecologic zones need to shift away from teff production, as the Northern Highlands agroecologic zone rightfully did so.[33]

Figure 3.10 Annual yield levels of crop categories and important crops in Central Highlands between 1997 and 2007



Source: Data from CSA (1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, and 2008).

Farmers in the Central Highlands agroecologic zone on average produced 1,359 KGs of agricultural output per hectare of cultivated land during the 1997-2007 period. On average, total agricultural yield levels have increased by 2.4 percent during the same period. This is low by comparison to the 4 percent nationwide average annual growth rate of total agricultural yield and it was in spite of the relatively higher average annual yield

[33] The only item the Central Highlands agroecologic zone performed poorer than nationwide yield level is barley. Otherwise, it had high land productivity levels producing at least 2.3 percent more sorghum than the national average to 21 percent more in teff. Its overall agricultural yield level was 3.5 percent higher than the national average. (All numbers are relative yield levels averaged over the period of 1997-2007).

growth rates of grains, cereals, pulses, and the 5 important cereals that on average accounted for 77 percent of the total cultivated area.[34]

One of the observations about this agroecologic zone is its high potential in maize production. Maize is largely grown in the Hararghe agroecologic zone, as the climatic conditions are more favorable. Given the favorable agroclimatic condition and the maize growing tradition I expected lower maize yields in Central Highlands, in particular relative to the Hararghe Agroecologic zone. But Central Highlands produced more per hectare than Hararghe in all years except 1997, and had larger yield than the national average in all years except 1998 and 2004. The perceived high maize yield potential in Northern Highlands can be supported by invoking the rising opportunity costs argument. That is, Central Highlands is using the acreage that is most suitable for maize production. The area that is allocated for maize production is larger in Central Highlands relative to Hararghe in absolute terms. But adjusting for the small size of total cultivated area in the Hararghe agroecologic zone, The Central Highlands agroecologic zone cultivated almost one-half the size cultivated in Hararghe, which is not small and may not sit well with the rising opportunity costs argument as does with the possibility that Central highlands actually has high maize growing potential.

Arussi/Bale

The Arussi/Bale agroecologic zone was the second largest contributor to nationwide total cultivated area. The Arussi and Bale administrative zones, which are the sampled administrative zones in this agroecologic zone, accounted for an average of 10 percent of the total cultivated area nationwide during the period between 1997 and 2007. Unlike in the Northern and Central Highlands teff played lesser role in the Arussi/Bale agroecologic zone. The most important crop in this agroecologic zone was wheat. On average, 32 percent of the total cultivated area was sown to wheat during the 1997-2007 period, 2.7 times the proportion allocated for teff. The next important crop was barley

[34] The 2.8 percent growth in yields ignores the first 3 years of sorghum yield data that showed highly volatile sorghum yields; otherwise the number is 4.2 percent.

accounting for an average of 21 percent of the total cultivated area during the same period. The proportion of the area sown to teff was a distant third, barely higher than the average accounted for by the fourth important crop, maize (Table 3.12).

Table 3.12 Cultivated area (1,000 hectares) under different crop categories and the proportion of total area accounted for by crop categories and crops in Arussi/Bale agroecologic zone between 1997 and 2007

Crop type	Year									
	1997	1998	1999	2000	2003	2004	2005	2006	2007	Average
	In thousands of hectares									
Total cultivated area	789	882	884	911	812	1249	1015	859	858	918
Area under grains	698	831	845	835	786	1232	992	841	838	877
Area under cereals	618	753	757	749	643	979	792	683	670	738
Area under pulses	80	78	88	62	45	93	81	78	95	78
Area under 5 major cereals[a]	586	724	733	627	869	942	774	658	652	729
	Proportions of total area sown to crop category/crop									
Proportion under grains[b]	0.88	0.94	0.96	0.92	0.968	0.99	0.98	0.98	0.976	0.95
Proportion under cereals[b]	0.78	0.85	0.86	0.82	0.79	0.78	0.78	0.79	0.78	0.81
Proportion under pulses[b]	0.10	0.09	0.10	0.07	0.06	0.07	0.08	0.09	0.11	0.09
Proportion under 5 major crops[b]	0.74	0.82	0.83	0.69	1.07	0.75	0.76	0.77	0.76	0.80
Proportion under teff[b]	0.08	0.11	0.13	0.13	0.16	0.10	0.11	0.11	0.15	0.12
Proportion under barley[b]	0.24	0.23	0.23	0.19	0.29	0.23	0.22	0.15	0.15	0.21
Proportion under wheat[b]	0.33	0.35	0.32	0.23	0.34	0.32	0.31	0.36	0.31	0.32
Proportion under maize[b]	0.08	0.10	0.11	0.10	0.23	0.09	0.09	0.11	0.11	0.11
Proportion under sorghum[b]	0.02	0.03	0.03	0.04	0.06	0.02	0.03	0.03	0.04	0.03

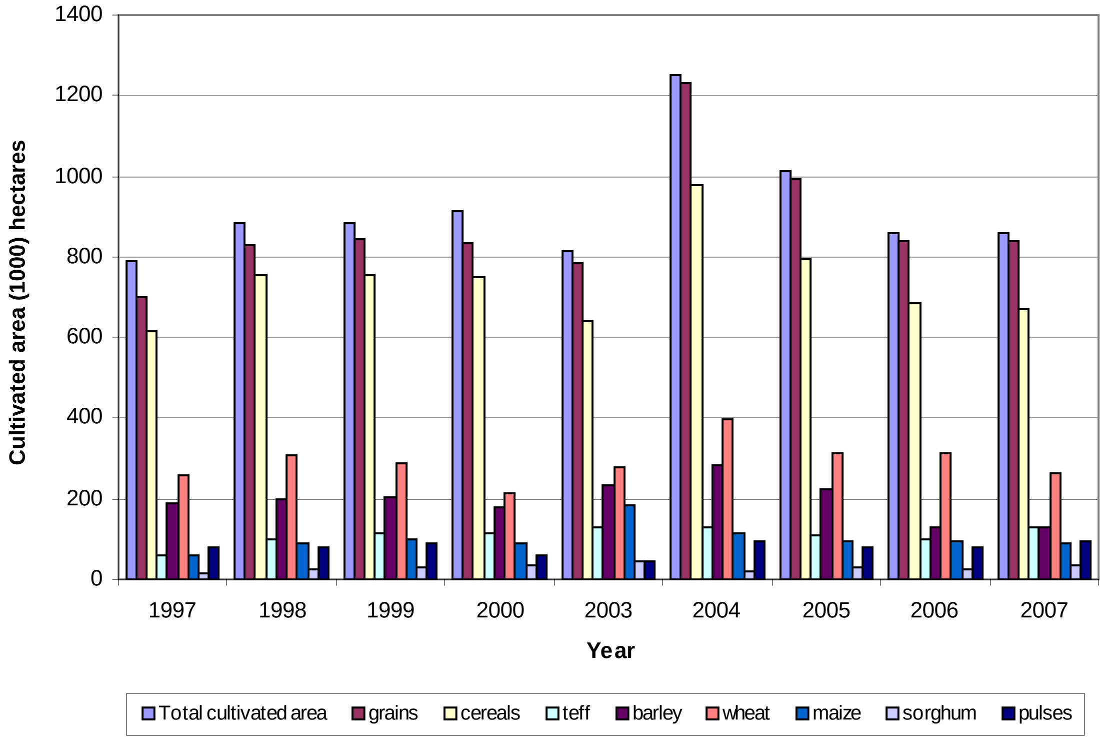
Source: CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

Notes: a. The 5 major cereals are teff, barley, wheat, maize, and barley.

b. The proportions are calculated out of total cultivated area.

While the Arussi/Bale agroecologic zone is somewhere in between Northern Highlands and Central Highlands in terms of the area allocated for grains in general, and pulses and cereals in particular, this agroecologic zone had the largest proportion of total cultivated area that was allocated for the five important crops, which on average accounted for 80 percent of the total cultivated area. Specifically, the importance associated with wheat cultivation in Arussi/Bale was almost tantamount to the one associated with teff in Northern highlands agroecologic zone. The importance of the area sown to grains and cereals is so vivid in this agroecologic zone that the growth rate of total cultivated area was the same as the growth rate of the area under cereals and grains for most of the periods between 1997 and 2007.

Figure 3.11 Trends in cultivated area under different crop categories and crops in Arussi/Bale agroecologic zone during 1997-2007



Source: CSA (1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, and 2008).

Farmers in Arussi/Bale agroecologic zone produced an average of 1,469 KGs of agricultural output per hectare of land they cultivated during the 1997-2007 period. Yield levels in this agroecologic zone are relatively higher, on average this agroecologic zone had 13 percent more yield than produced nationwide, 9 percent higher yield than in Central Highlands, and on average 12 percent higher yield than in Northern Highlands. During the 1997-2007 period, average yield levels of the most important crop, wheat was at least 10 percent higher in Arussi/Bale than wheat yields in any other agroecologic zones and nationwide yield levels while yield levels of the second most important crop, barley, were at least 20 percent larger.

Table 3.13 Annual yield levels of crop categories and crops in Arussi/Bale agroecologic zone between 1997 and 2007

Crop type	Year									Average
	1997	1998	1999	2000	2003	2004	2005	2006	2007	
Yield	Kilograms per hectare									
Total agriculture	1410	1163	1203	1360	1638	1633	1570	1575	1670	1469
Grains	1521	1203	1230	1428	1123	1499	1409	1460	1555	1381
Cereals	1568	1226	1260	1468	1150	1666	1561	1599	1671	1463
Pulses	1156	986	974	1515	1224	1115	1003	1061	1248	1143
Average of 5 major cereals	1539	1252	1230	1495	932	1571	1589	1657	1653	1435
Teff	915	865	840	757	521	784	759	779	1023	805
Barley	1483	1104	1126	1521	757	1741	1491	1630	1674	1392
Wheat	1696	1250	1378	2501	916	1883	1695	1739	1927	1665
Maize	2135	1788	1577	1563	806	1853	2211	1985	1890	1756
Sorghum	1468	1253		1136	1659	1594	1788	2153	1752	1600

	Period								Average
Annual growth rates	97-98	98-99	99-00	00-03	03-04	04-05	05-06	06-07	
Total agriculture	-0.176	0.035	0.130	0.068	-0.003	-0.039	0.003	0.060	0.010
Grains	-0.209	0.022	0.161	-0.071	0.335	-0.060	0.036	0.065	0.035
Cereals	-0.218	0.028	0.166	-0.072	0.448	-0.063	0.025	0.045	0.045
Pulses	-0.148	-0.012	0.556	-0.064	-0.089	-0.101	0.057	0.176	0.047
Average of 5 major cereals	-0.187	-0.017	0.216	-0.126	0.686	0.011	0.043	-0.003	0.078
Teff	-0.054	-0.029	-0.099	-0.104	0.505	-0.032	0.026	0.312	0.066
Barley	-0.255	0.020	0.352	-0.167	1.298	-0.144	0.094	0.027	0.153
Wheat	-0.263	0.103	0.815	-0.211	1.055	-0.100	0.026	0.108	0.192
Maize	-0.162	-0.118	-0.009	-0.161	1.299	0.193	-0.10	-0.048	0.111
Sorghum	-0.147	--	-0.05[a]	0.461	-0.040	0.122	0.204	-0.186	0.053

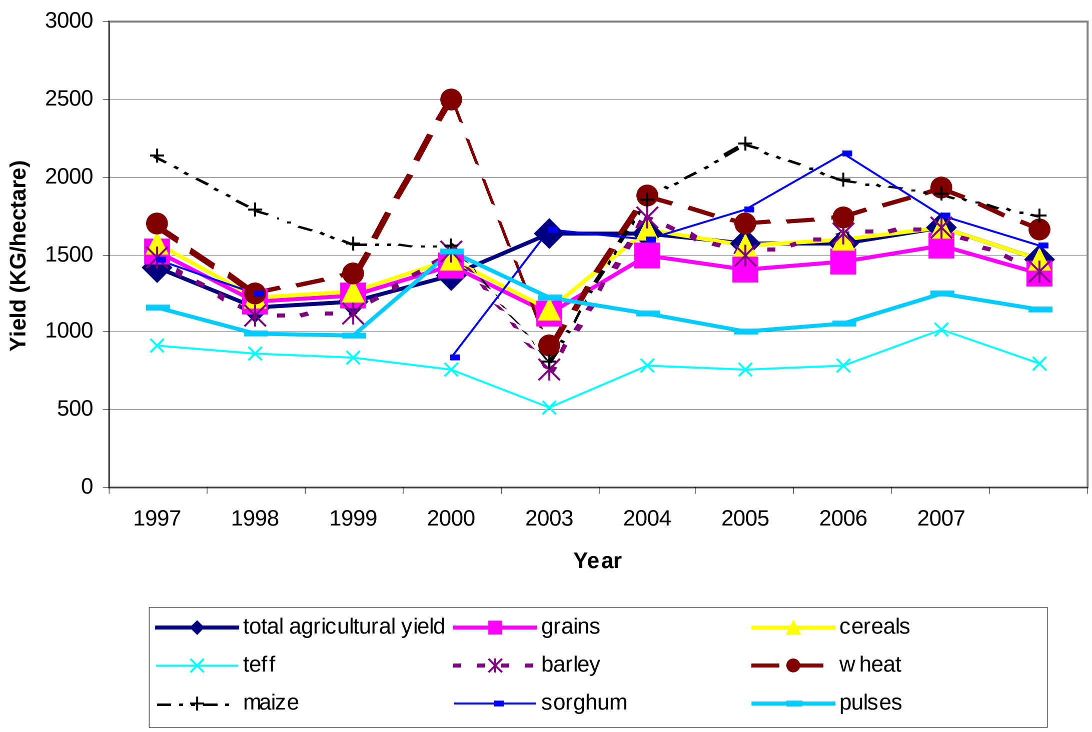
Source: Data from CSA (1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, and 2008).

Note: a. Average annual growth rate between 1998 and 2000.

Although yield levels in Arussi/Bale agroecologic zone were significantly higher in almost all crop categories than the nationwide average and relative to all but the Hararghe agroecologic zone, it experienced one of the slowest growth rates in yield. Total agricultural yield increased by an average annual rate of only 1 percent. This is in spite of the fact that the difference between average annual growth rates of output and cultivated area was 10 percent. Cereals and pulses yield levels grew by relatively higher rates of 4.5 and 4.7 percents, respectively. The two most important crops in this agroecologic zone, wheat and barley, had the fastest growing yield levels at 19 and 15 percent average annual growth rate. Arussi/Bale had higher wheat and barley yield levels than any other agroecologic zone, including the Hararghe agroecologic zone, which on average had 78 percent of barley and 82 percent of wheat yields of Arussi/Bale.

Average annual yield levels of the 5 important crops declined by 19 percent between 1997 and 1998. During this period total agricultural yields declined by 18, percent, grains by 21 percent, and cereals by 22 percent. The two crops that suffered the worst decline in yields levels were wheat and barley. If we were to ignore the decline in yields between 1997 and 1998 then average annual growth in total agricultural crop yield would be 3.6 percent. Considering the 1998-2007 period, wheat yields have on average grown by 26 percent and barley yields by 21 percent.

Figure 3.12 Annual yield levels of crop categories and important crops in Arussi/Bale between 1997 and 2007



Source: Data from CSA (1998, 1999, 2000, 2001, 2004, 2005, 2006, 2007, and 2008).

Hararghe

The Hararghe agroecologic zone comprised the third largest cultivated area, accounting for about 13 percent of the total area cultivated in the sample agroecologic zones. However, the total cultivated area of this agroecologic zone, which averaged 0.402 million hectares between 1997 and 2007, was less than one-half the area that was cultivated in the second largest agroecologic zone, Arussi/Bale. Total cultivated area increased at an average annual rate of 9 percent, this was the second fastest area expansion next to the growth rate in Northern Highlands.

Table 3.14 Cultivated area (1,000 hectares) under different crop categories and the proportion of total area accounted for by crop categories and crops in Hararghe agroecologic zone between 1997 and 2007

Crop type	Year									Average
	1997	1998	1999	2000	2003	2004	2005	2006	2007	
	In thousands of hectres									
Total cultivated area	251	309	338	418	426	394	493	485	501	402
Area under grains	242	294	325	404	356	365	454	449	471	373
Area under cereals	227	272	302	366	316	298	378	376	411	327
Area under pulses	15	22	23	38	27	46	39	39	35	31
Area under 5 major cereals[a]	222	269	299	363	312	295	372	372	404	323
	Proportions of total area sown to crop category/crop									
Proportion under grains[b]	0.96	0.95	0.96	0.97	0.835	0.93	0.92	0.93	0.940	0.93
Proportion under cereals[b]	0.90	0.88	0.89	0.88	0.74	0.76	0.77	0.77	0.82	0.82
Proportion under pulses[b]	0.06	0.07	0.07	0.09	0.06	0.12	0.08	0.08	0.07	0.08
Proportion under 5 major crops[b]	0.88	0.87	0.88	0.87	0.73	0.75	0.75	0.77	0.81	0.81
Proportion under teff[b]	0.02	0.04	0.04	0.04	0.03	0.04	0.03	0.04	0.02	0.03
Proportion under barley[b]	0.01	0.03	0.02	0.02	0.01	0.02	0.03	0.03	0.03	0.02
Proportion under wheat[b]	0.02	0.03	0.04	0.05	0.03	0.04	0.10	0.05	0.02	0.04
Proportion under maize[b]	0.26	0.36	0.34	0.34	0.23	0.23	0.20	0.26	0.27	0.28
Proportion under sorghum[b]	0.56	0.42	0.45	0.42	0.43	0.41	0.38	0.38	0.46	0.44

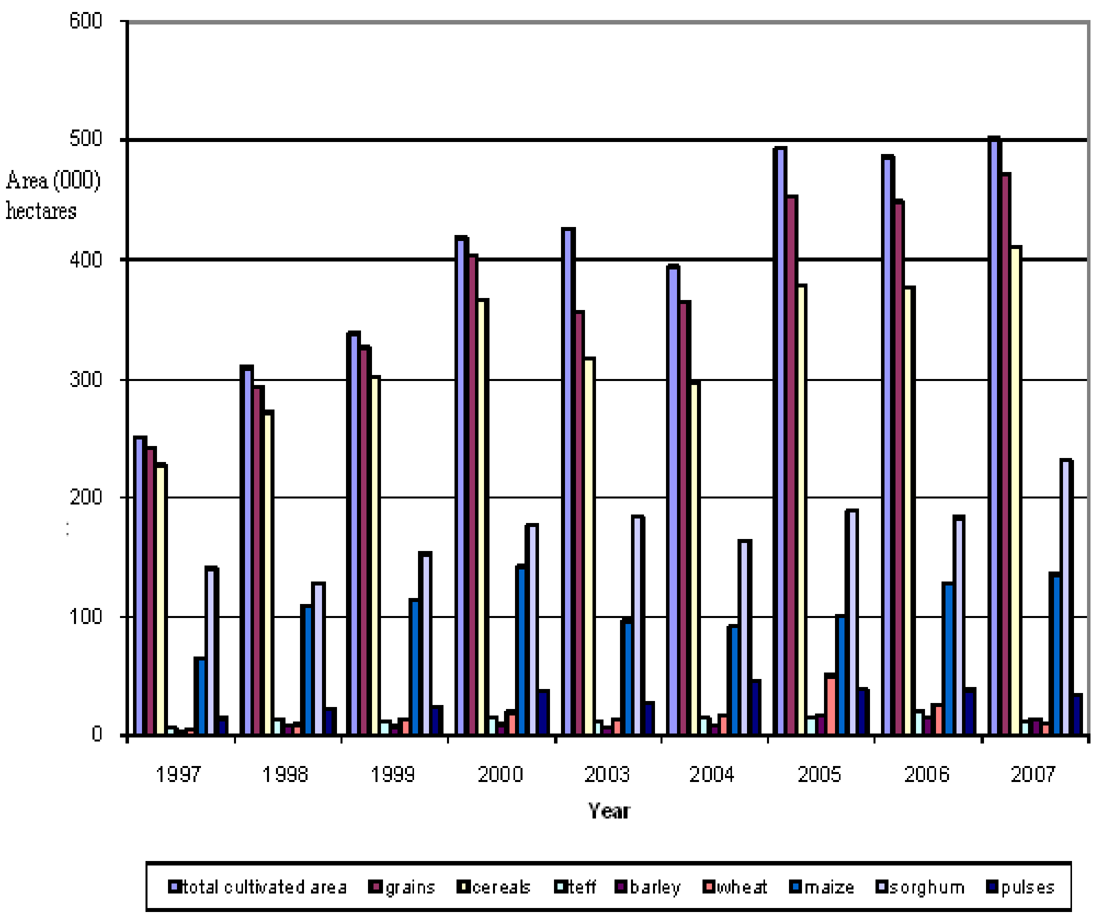
Source: CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

Notes: a. The 5 major cereals are teff, barley, wheat, maize, and barley.

b. The proportions are calculated out of total cultivated area.

Just as in the previously discussed agroecologic zones grains production constituted the most important category in Hararghe, accounting for an average of 93 percent of the total area cultivated during the 1997-2007 period. Out of the 93 percent, cereals and pulses accounted for 82 and 8 percent, respectively, which implies that oilseeds accounted for an average of 3 percent of the total area that was cultivated during the same period. The entire area that was allocated for cereals was taken up almost entirely by the five important cereals, which on average accounted for 99 percent of the area sown to cereals. Unlike in Northern and Central Highlands, where teff was the important crop, and in Arussi/Bale, where wheat and barley were important, the Hararghe agroecologic zone concentrated in growing sorghum and maize. The emphasis on these crops is unlike any other. The two crops on average accounted for 72 percent of the total area cultivated or accounted for 87 percent of the area sown to cereals. Wheat, teff, and barley, together accounted for less than a third of the area that was accounted for by the second important crop, maize.

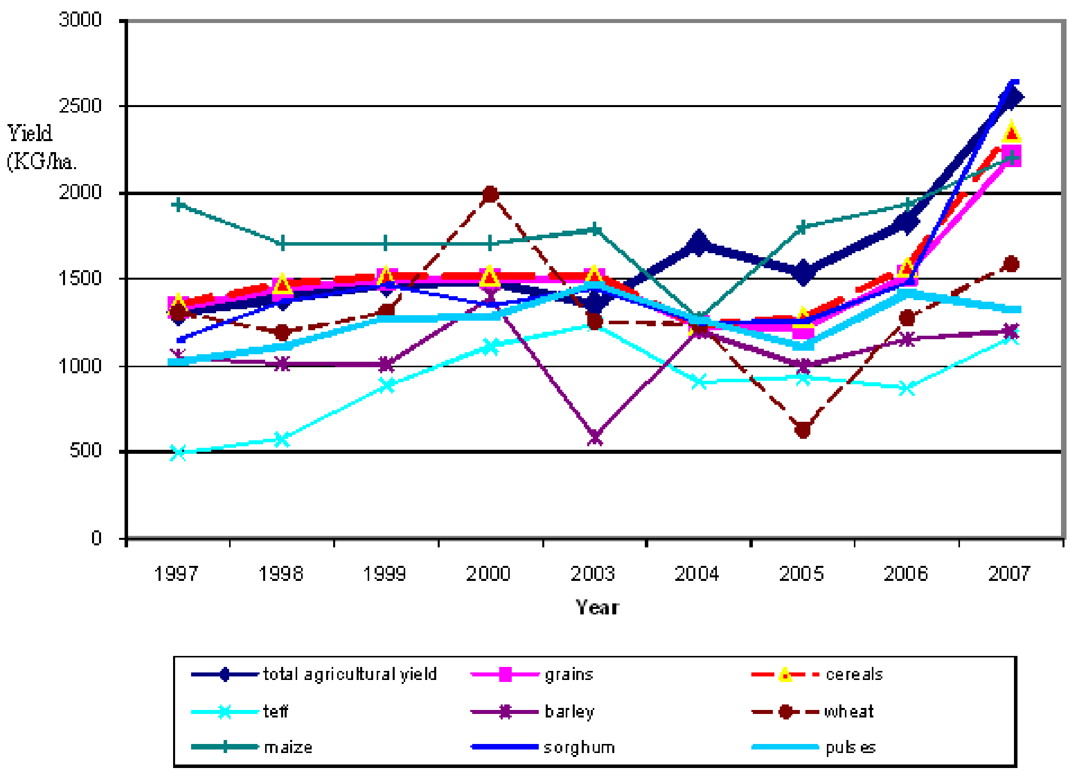
Figure 3.13 Trends in cultivated area under different crop categories and crops in Hararghe agroecologic zone during 1997-2007



Source: Data from CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

During the 1997-2007 period total cultivated area grew at an average annual rate of 9 percent. Although the area allocated for the most important crop, sorghum, grew at a lower average annual rate than growth in total cultivated area, 7 percent, it was compensated by a relatively faster growth rate of the area that was sown to maize, which had an average annual growth rate of 16 percent. Taken together, the area sown to the two most important crops grew at exactly the same average annual growth rate of total cultivated area, 9 percent. Judging from the trend of the proportion of cultivated land that was allocated for different crops and categories during this period, farmers in this agroecologic zone did not shift away from or into a specific crop.

Figure 3.14 Annual yield levels of crop categories and important crops in Hararghe between 1997 and 2007



Source: Data from CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

Farmers in the Hararghe agroecologic zone harvested an average of 1,627 KGs of agricultural output per hectare of land they cultivated during the 1997-2007 period. This average annual yield is almost the same as the combined average annual yield of sorghum and maize, which was 1,638 KGs per hectare for the same period. In addition to the significantly high yield levels than in other agroecologic zones, annual yield levels grew at a relatively fast average rate of 11 percent. Specifically, the crop that on average accounted for 44 percent of the total cultivated area, sorghum, had yield levels that grew at an average annual rate of 14 percent. Given the stagnant maize yields, the Hararghe agroecologic zone performed better in maize yield only relative to Northern Highlands agroecologic zone while it performed better in sorghum production than almost every other agroecologic zone. In Hararghe, the three fastest growing yields levels were registered from the areas that were sown to barley, wheat and teff. But given the insignificant contribution of barley, wheat, and teff to total cultivated area yield levels of grains and the 5 important crops grew at an average annual growth rate that was close to the 7.2 percent average annual growth rate of the combined yields of sorghum and maize.

Enset

As was stated earlier, this agroecologic zone is named after the staple crop in the region, enset. However, CSA made no mention of root crops, which includes enset, before the 2004 publication. The five publications since 2004 contain root crops data but they did not include data on the area cultivated to enset nor on enset production. As a result of this the description of this agroecologic zone presented below should be taken with the qualification that the most important staple crop is not covered. The other wrinkle with the Enset agroecologic zone data set is that data is missing for North Omo administrative zone from 2004 onwards. For the 2004-2007 period, while calculating the data for Enset agroecologic zone I took into account the average percentage of area, 49 percent, and production, 40 percent, that this administrative zone accounted for in the previous years, and used the average growth rate of area and production in the remaining administrative zones while calculating the respective growth for North Omo administrative zone.

Farmers in the Enset agroecologic zone on average cultivated 0.324 million hectares of land during the 1997-2007 period. Even after correcting for the missing data of the North

Omo administrative zone there is a clear distinction between average cultivated area in the 1997-2000 period, which was 0.434 million hectares, and in the 2003-2007 period that averaged 0.236 million hectares. Total cultivated area increased by an average annual growth rate of 5 percent during the period. The area sown to barley had the largest average annual growth rate of 64 percent. However, the area under barley massively varied with a variance of 0.608 million hectares, implying that this growth rate could be misleading. The remaining crops and crop categories increased by an average annual growth rate that ranged from 4 to 13 percent.

Table 3.15 Cultivated area (1,000 hectares) under different crop categories and the proportion of total area accounted for by crop categories and crops in the Enset agroecologic zone between 1997 and 2007

Crop type	Year									
	1997	1998	1999	2000	2003	2004	2005	2006	2007	Average
	In thousands of hectares									
Total cultivated area	313	418	407	597	324	206	208	207	233	324
Area under grains	311	416	405	594	324	189	190	189	207	314
Area under cereals	274	376	350	510	149	161	160	164	177	258
Area under pulses	38	40	55	84	156	29	27	25	29	54
Area under 5 major cereals[a]	253	374	347	506	142	147	153	153	162	249
	Proportions of total area sown to crop category/crop									
Proportion under grains[b]	1.00	1.00	1.00	0.99	1.000	0.92	0.91	0.91	0.886	0.96
Proportion under cereals[b]	0.87	0.90	0.86	0.85	0.46	0.78	0.77	0.79	0.76	0.78
Proportion under pulses[b]	0.12	0.10	0.13	0.14	0.48	0.14	0.13	0.12	0.12	0.17
Proportion under 5 major crops[b]	0.81	0.89	0.85	0.85	0.44	0.72	0.73	0.74	0.70	0.75
Proportion under teff[b]	0.26	0.29	0.27	0.19	0.15	0.25	0.25	0.28	0.22	0.24
Proportion under barley[b]	0.05	0.19	0.09	0.13	0.06	0.13	0.13	0.13	0.12	0.12
Proportion under wheat[b]	0.09	0.09	0.08	0.08	0.08	0.17	0.12	0.14	0.12	0.11
Proportion under maize[b]	0.31	0.23	0.32	0.35	0.11	0.14	0.16	0.14	0.19	0.22
Proportion under sorghum[b]	0.11	0.09	0.09	0.11	0.03	0.03	0.06	0.05	0.04	0.07

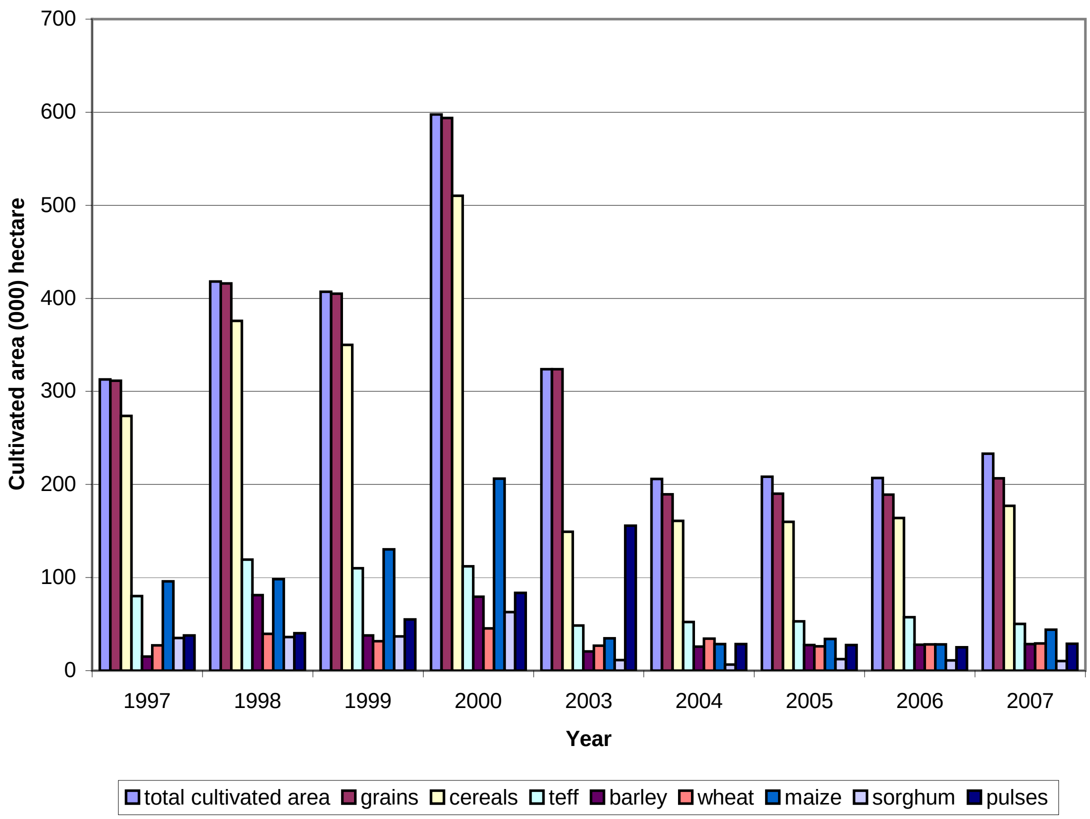
Source: CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

Notes: a. The 5 major cereals are teff, barley, wheat, maize, and barley.

b. The proportions are calculated out of total cultivated area.

The area that was allocated for grains production was as high as in the other agroecologic zones, with 96 percent of the total cultivated area sown to grains. On average, cereals accounted for 78 percent of total cultivated area. Teff and maize were by far the two important crops accounting for an average of 24 and 22 percent of the total cultivated area, respectively. On average, the area under teff and maize were twice the size of the respective area that was sown to barley and wheat, the third and fourth important crops. The category of the five important crops accounted for an average of 75 percent of the total cultivated area. The importance that was associated with maize had declined after 2000, the proportion of total cultivated area sown to maize declined from an average of over 30 percent during the 1997-2000 period to an average of less than 15 percent during 2003 to 2007. The proportion of the area that was sown to teff remained fairly stable.

Figure 3.15 Trends in cultivated area under different crop categories and crops in the Enset agroecologic zone during 1997-2007



Source: Data from CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

Farmers in the Enset agroecologic zone on average produced 1,522 Kilograms of agricultural output from each hectare of land they cultivated. Yield levels varied from 1,053 KGs in 1998 to the highest yield of 1,977 KGs in 2007. Annual yield levels increased at an average annual rate of about 5 percent. Average annual growth rate of yield was higher than the difference between average annual growth rates of output and area of cultivated land, which was less than 3 percent.

Table 3.16 Annual yield levels of crop categories and crops in the Enset growing agroecologic zone between 1997 and 2007

Crop type	1997	1998	1999	2000	2003	2004	2005	2006	2007	Average
Yield	Kilograms per hectare									
Total agriculture	1216	1053	1108	1187	1529	1861	1858	1909	1977	1522
Grains	1220	1058	1137	736	624	1335	1200	1300	1331	1105
Cereals	1277	1093	1186	738	1298	1373	1257	1346	1380	1217
Pulses	806	723	820	724	832	1119	952	1001	1044	891
Average of 5 major cereals	1060	964	980	1030	1291	1396	1291	1430	1393	1204
Teff	660	532	625	698	712	910	741	819	974	741
Barley	306	307	622	474	1062	1222	1025	1112	993	791
Wheat	1207	1071	925	1256	1763	1737	1604	1688	1575	1425
Maize	1924	1969	1698	1713	1737	1914	2038	2336	2135	1940
Sorghum	1203	939	1031	1011	1181	1198	1048	1194	1287	1121

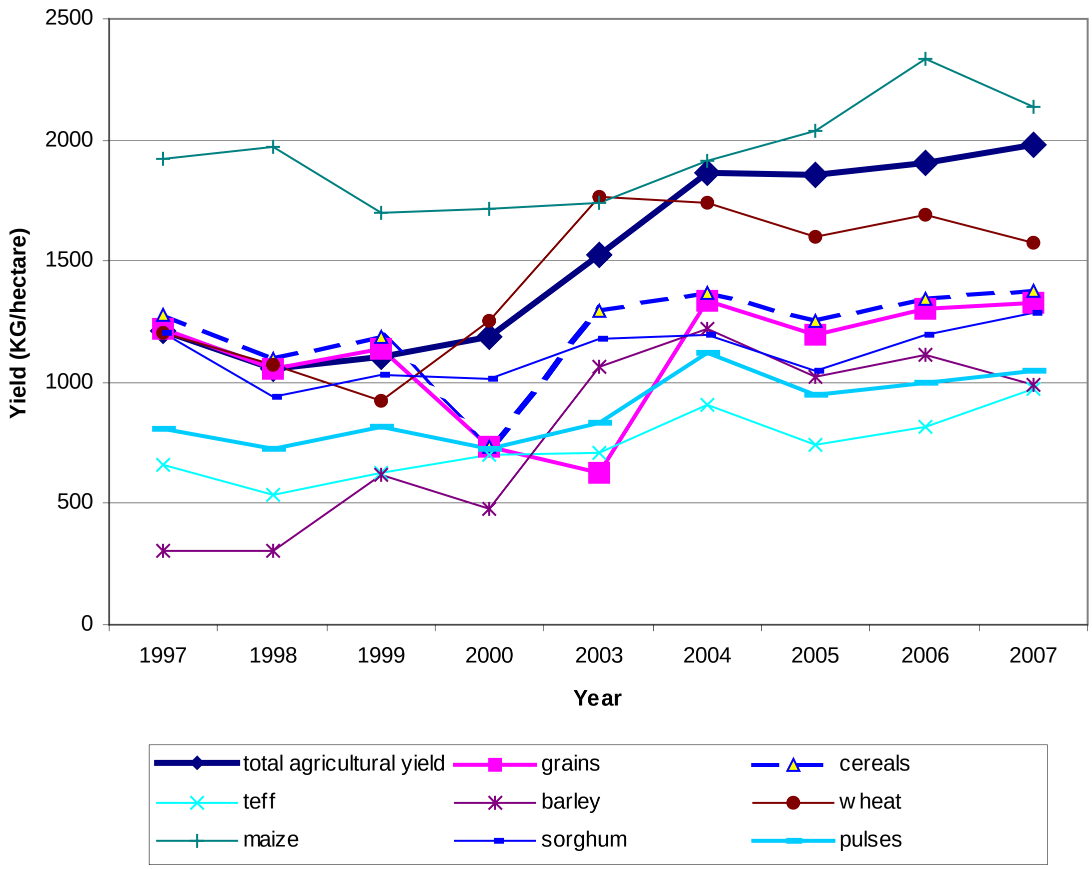
Annual growth rates	98-97	99-98	00-99	03-00	04-03	05-04	06-05	07-06	Average
Total agriculture	-0.134	0.052	0.071	0.096	0.217	-0.002	0.027	0.036	0.045
Grains	-0.133	0.075	-0.352	-0.051	1.138	-0.101	0.084	0.024	0.085
Cereals	-0.144	0.085	-0.378	0.253	0.058	-0.085	0.071	0.025	-0.014
Pulses	-0.104	0.135	-0.117	0.049	0.345	-0.149	0.051	0.043	0.032
Average of 5 major cereals	-0.091	0.017	0.051	0.084	0.081	-0.075	0.108	-0.026	0.019
Teff	-0.193	0.174	0.117	0.007	0.277	-0.186	0.107	0.189	0.061
Barley	0.003	1.025	-0.237	0.413	0.150	-0.161	0.085	-0.106	0.146
Wheat	-0.112	-0.137	0.358	0.135	-0.015	-0.077	0.052	-0.067	0.017
Maize	0.024	-0.138	0.008	0.005	0.101	0.065	0.147	-0.086	0.016
Sorghum	-0.219	0.098	0.077	0.168	0.015	-0.126	0.139	0.078	0.029

Source: Data from CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

Annual grain yield levels increased by an average annual growth rate of 8.5 percent. This growth rate, which is 88 percent higher than the average annual growth rate of total agricultural yield, does not add up with the fact that grains accounted for 96 percent of total cultivated area. The same goes for cereals yields that on average declined by 1.4

percent [while grains yields increased], as cereals on average accounted for 78 percent of total cultivated area and for 82 percent of the area under grains. Ignoring the 1997-98 period, when yield levels of most crops and crop categories fell down by double digits, improved the puzzling numbers but did not eliminate them entirely. During the 1998-2007 period average annual growth rate of total agricultural yields was 7 percent, average annual growth rate of grain yields was 12 percent, while cereal yields increased at an average annual rate of about 1 percent.

Figure 3.16 Annual yield levels of crop categories and important crops in the Enset growing agroecologic zone between 1997 and 2007



Source: Data from CSA (1998, 1999, 2000,2001, 2004, 2005, 2006, 2007, and 2008).

Although teff is the most important crop in this agroecologic zone, average annual teff yield of 741 KGs per hectare of land sown to teff is low by comparison even to yield levels of the resource poor agroecologic zone, Northern Highlands. Annual teff yields of the enset agroecologic zone were on average 78 percent of the yield levels in Central Highlands and 92 percent of yield levels in Northern Highlands agroecologic zone, the two agroecologic zones with large teff producing sub sectors. The Enset agroecologic zone performed relatively better in the second important crop, maize, producing yield levels that were on average 10 percent higher than yield levels in the Hararghe agroecologic zone, and producing on average about 96 percent of the yield levels of Central Highlands, an agroecologic zone with some of the highest annual yields of maize.

3.5 Features of Ethiopian Agriculture: Household Level Data

In this section, I use data from five of the six rounds of Ethiopian Rural Household Survey (ERHS) that were described in chapter 2. The total number of households included in the panel data is 6,486, 92 percent of the total number of 7,082 respondents in the surveys. I will describe important details of the panel data in sub-section 3.5.1. Section 3.5.2 entails an examination of the data from the fifth round ERHS survey conducted in 1999. Unlike other rounds, the fifth round is rich with details about the pattern of modern input use. Moreover, the survey data make it possible to associate the use of specific inputs with specific outputs, unlike other rounds where it is only possible to link total input use with the total value of production for each of the surveyed households.

3.5.1 Input Use, Production Patterns, and Constraints: Panel Data

Of the 1,224 households surveyed in 1999 and included in the panel data, 81 percent had male household heads. The share of female-headed households tends to rise as the age of the household head rises, consistent with the notion that women become head of a household upon the death of male heads or separation from their partners.

Sixty eight percent of the 1,224 household heads were illiterate, about 15 percent knew how to read or write through some formal or informal schooling, while 17 percent or 204 of them were literate, roughly in line with the national averages reported above. The difference in literacy rates between the two sexes is more apparent in this group of households: 90 percent of female heads of households were illiterate compared with 63 percent of male household heads. The proportion of female heads of households that were literate was about 4 percent compared with 20 percent of males who were literate.

Table 3.17 presents the real value of output in birr. For all survey rounds, data on market prices of each commodity for each woreda that were collected alongside the surveys were used in combination with the household data to calculate these values for each household. As discussed in chapter two, the conversion of the items produced into value of output that is aggregated at a household level was needed because data on many of the inputs used were collected at a household level while data on size of cultivated land and output produced were collected at the plot level.

The average real value of output has generally increased in the sample period, the bumper harvest in 1997 being an exception. On average, households earned about 1,805 birr from the meher harvests averaging across each of the survey years. The real value of output grew by an average annual rate of 7 percent between 1994 and 2004. During this period food prices have been relatively stable in Ethiopia; indexing year 2000 food prices to a base value of 100, the only higher price index of 101 was reported in 1999 (WDI 2007). The price indices for 1994 and 2003 were 84 and 92. The average annual growth in food price indices between 1995 and 2003 was less than 0.1 percent.[35] I used peasant association level food price indices to deflate the value of output of farm households included in the surveys. Data on the food prices were purposefully collected and food price indices were calculated as Laspeyers index, based on peasant association prices using average shares in 1994 as the weights. Peasant association level food price indices

[35] WDI 2007 does not have information on food price indices of 2004 for Ethiopia while WDI 2008 does not include this variable.

increased relatively faster than aggregate food price indices. Average annual growth rate of food price index in the surveyed peasant associations was 4 percent.

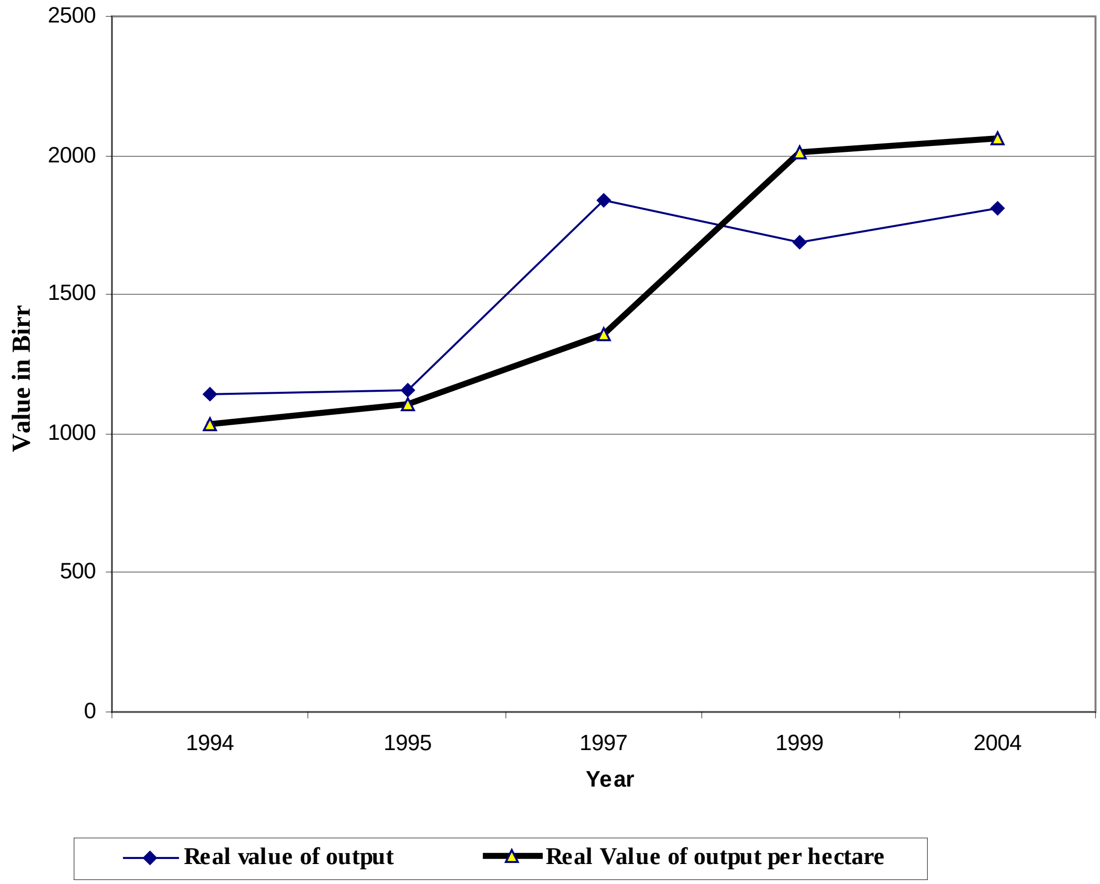
Table 3.17 Average input use and production patterns of sample households in Ethiopia during the 1994 to 2004 period

Variable	Units	1994	1995	1997	1999	2004
Real value of output	Birr	1144	1153	1836	1687	1811
Real Value of output per hectare	Birr	1037	1108	1354	2012	2064
Cultivated area	Hectare	1.2	1.2	1.9	0.9	1
Average land quality	Index	2.5	2.4	2.1	2.2	2.2
Number of plots cultivated	Number	3.3	3.6	4	4.9	4.5
Household members over 16 of age	Number	3.3	3.3	3.9	3	2.7
Fertilizer use	Kilograms	38	41.7	48.6	49.6	27.8
Hoes used by the household	Number	0.8	0.9	0.9	1.3	1.1
Ploughs used by the household	Number	0.8	1.1	1.1	1.4	1.1
Oxen used for ploughing	Number	1.3	1.3	1.7	1.4	0.9

Source: ERHS rounds 1, 3,4, 5, and 6.

Real value of output per hectare of cultivated land consistently grew over the period 1994 to 2004. On average, households produced about 1,515 birr worth of output per hectare of cultivated land over the period reported in Table 3.17. The average annual growth rate of real value of output per hectare over the period was about 10 percent. Over the same period households cultivated 1.24 hectares on average. Cultivated area increased from 1994 to 1997 then declined in 1999, but rebounded in 2004. Average cultivated area per farm household declined by 17 percent when comparing only 1994 and 2004. However, the average annual rate of change of cultivated land per household is positive at about 1.3 percent mainly due to the higher growth rate between 1995 and 1997. Substituting the average land holding per household in 1997 with the average land holding of 1994, 1995, 1999, and 2004, the average cultivated area declined at average annual rate of 2.7 percent during 1994 through 2004. This is indicative of the current trend in declining land holding per household. With continued growth in population and the already densely settled farming land, such decline in cultivated area per household will exacerbate the problems subsistence agriculture is facing in Ethiopia. One important objective of the following chapter is to study the change in value of output and explain its growth-paying particular attention to the extent of improvement that is attributed to the use of modern inputs.

Figure 3.17 Average values of output and output per hectare deflated using peasant association level food price indices.



Source: Calculated data from Ethiopian Rural Household Survey rounds 1, 3, 4, 5, and 6.

On average, each household cultivated four plots of land. A plot is defined as an agricultural land unit that is not physically connected to other agricultural lands farmed by the same holder (Dercon and Hodinott 2004). Consequently farmers may be operating plots that are sufficiently far apart that each plot may have its own agroecological characteristics. Data on the size of each plot is collected along with its average slope and quality in terms of general nutrient status. To account for land quality I created a composite variable that takes both slope and nutrient status into consideration. The variable was created by multiplying the value for the slope of the land (1=flat, 2=hill or 3=high-hill/high land) by the value for the fertility of the land (1=fertile, 2=moderately fertile and 3=less fertile). A plot with a value of 1 is deemed “ideal” land while plots with the least desirable quality have a value of 9 for land quality. Table 3.17 reports average land quality of the plots owned by each household in each period. While average land quality was 2.3 during the period the surveys were conducted, it had generally declined over the years.

Fertilizer was used by an average of 521 (or 40 percent) of the households over the 1994 to 2004 period; this varied from 51 percent in 1999 to 24 percent in 2004. Among those households that used fertilizer, an average of 103 kilograms of fertilizer was used between 1994 and 2004. The rate of fertilizer use per household among those that use fertilizer fluctuated between an average of 117 kilograms per household in 2004 to 96 kilograms in 1994. In this sub-sample average fertilizer use increased by an average of 3.7 percent per year between 1994 and 2004. Considering the entire sample during the period of 1994-2004, fertilizer use averaged 41 kilograms per household while average fertilizer use increased by 2.5 percent per year.

On average 34 kilograms of fertilizer was applied on each hectare of cultivated land during the 1994-2004 period. This rate of application barely budged over time, increasing by an average of only 4.5 percent per year between 1994 and 2004. Among those households that used fertilizer during these years, on average 84 kilograms of fertilizer was applied on each hectare of cultivated land while per hectare fertilizer application rates grew by an average of 6 percent per year between 1994 and 2004.

Farmers use a combination of family, shared, hired and own labor. Each of the surveys collected data on the use of some or all of these forms of labor. The details by which labor data were collected varied from one survey to the next. There were differences in terms of phrasing, arrangement, and content for each round of the survey. Three of the rounds collected recall data on labor use for the entire meher season while rounds three and four collected data only on the 30 days preceding the interview. Close examination of the labor data and consultation with researchers that conducted the surveys revealed that the labor variable has significant measurement errors. Those knowledgeable about these details advised me to substitute this variable with the number of household members 16 years of age and above, as most household members of these ages participated in farming at one time or another during the agricultural season and thus the variable can be used as a proxy for labor input. This variable will be used in the analysis that I conduct in chapter three. Each household had an average of 3.3 members aged 16 and above during the period 1994-2004. This figure ranged between 2.7 in 2004 to 3.9 in 1997. The total number of household members averaged 6.1, indicating that about 50 percent of the residents in the sampled household were children under the age of 16.

Data on animals owned by each household were collected in all of the rounds. The data on the number and quality of animals were converted both into a monetary value and livestock equivalent units by researchers at IFPRI.[36] Table 3.18 presents the average value of these estimates. The number of cattle owned by sample households averaged 4.1, ranging from 3.5 in 1997 and 2004 to 4.9 in 1994. In general the average number of cattle owned declined over the period 1994 to 2004. The average monetary value of these cattle was 2,204 birr over the years while the livestock units owned averaged 2.9. Oxen are an important source of ploughing power for Ethiopian farmers. The sampled households owned an average of 1.3 oxen that were used for ploughing.

The surveys collected data also on whether the head of the household was too sick to farm and if the household experienced shortage of ploughing oxen at one or more point during the season. The average value of the first variable was 0.2 indicating that 20 percent of household heads were too sick to farm while on average 30 percent of the farmers had faced shortage of farming oxen during each of the meher seasons in 1994, 1995, 1997, 1999, and 2004.

[36] Livestock units converts the stock of animals a household owns into livestock equivalent units using the value of each animal relative to a livestock while livestock value is the monetary value of the livestock equivalent units a household owns valued at local average prices during the given period.

Table 3.18 Household and village level characteristics of sample households in Ethiopia during the 1994 to 2004 period

Variable	Units	1994	1995	1997	1999	2004
Cattle owned	Number	4.9	4.8	3.5	3.8	3.5
Livestock value	Birr	2054.9	1818.2	2476.7	1981.9	2688.7
Livestock units	Index	2.6	2.5	3.3	3	3
Education level of head of the household	Grade	0.5	0.5	0.6	0.6	0.6
Household size	Number	6.3	6.2	6	6.1	5.7
Was there shortage of ploughing oxen?	1 if yes, 0 if no	0.4	0.3	0.4	0.3	0.3
Was household head too sick to farm?	1 if yes, 0 if no	0.2	0.1	0.2	0.2	0.2
Did household participate in NEP?	1 if yes, 0 if no	0.1	0	0.1	0.1	0.2
Did household suffer from draught?	1 if yes, 0 if no	0.3	0.2	0	0	0

Source: ERHS rounds 1, 3,4, 5, and 6.

Geographic, ecological, social, and farm implement ownership data collected by IFPRI as an adjunct to the Ethiopian Rural Household Surveys and made available for this study provide important supplemental information on agroecological and technological attributes at peasant association level.[37] These data are presented in Table 3.19. In the survey years of 1994, 1995, 1997, 1999, and 2004, rainfall averaged 978 millimeters per year in the peasant associations where the sampled households resided, and an average of 10 percent of the households suffered from drought. The mean elevation of these households was 2,092 meters above sea level. Households had to travel significant distances to access essential services. The average distance of the households to the nearest health center was 21 kilometers while the nearest market was, on average, 26 kilometers away from where the households resided. The average distance between the households and the closest peasant association center was 24 kilometers while the nearest peasant association and cooperative office were over 60 kilometers away. On average each household owned 1 hoe and 1 plough while only 10 percent of the households participated in the New Extension Program provided by the government agriculture agency.

[37] I thank John Hoddinott and Yesehaq Yohannes of IFPRI for providing me these data.

Table 3.19 Village level characteristics of sample households in Ethiopia during the 1994 to 2004 period

Variable	Units	1994	1995	1997	1999	2004
Agricultural extension officers near PA	Number	0.7	0.7	0.7	0.9	0.9
Distance to health center	Kilometers	21.1	21.9	21.5	21.2	20.7
Distance to closest market	Kilometers	25.1	25.9	25.5	26.1	25
Distance to nearest PA center	Kilometers	24.7	24.4	23.5	24.3	24.9
Distance to village PA office	Kilometers	61	60.9	60.9	60.9	61.5
Distance to cooperative office	Kilometers	62.1	62	62	61.8	62
Average annual rain	Millimeters	908.8	1008	1070	961.1	942.3
Mean elevation	Meters	2089	2083	2081	2101	2110

Source: ERHS rounds 1, 3, 4, 5, and 6.

3.5.2 Input Use, Production Patterns and Constraints: 1999 ERHS Data

In addition to the 18 peasant associations (PAs) included in survey rounds 1, 3, 4, and 6, survey round 5 included 3 additional PAs with 346 more households that were not surveyed in any other round. In the following sections I will briefly discuss the special features of this round of data set.

Traditional Input use Patterns

In the 1,606 households for which data on family size were available, there lived 8,487 members, that is, an average household had about 5 members. On average, each household used about 87 days of male labor, women contributed 22 days of work, and children worked for 30 days.

The 1,681 households cultivated a total of 6,736 plots in the 1999 meher season; about 4 plots per household. Fifteen percent of the plots were sown to teff, 11 percent to barley, 10 percent to enset, 10 percent to maize, about 10 percent to wheat, and 9 percent to coffee (Table 3.20). The total land area of 6,712 of the plots, for which data on land size was available, was 1,931 hectares; each plot averaged about 0.29 hectares. Teff was sown on 463 hectares (24 percent) of the total area. Although maize and wheat rank fourth and fifth in terms of the number of plots on which they were sown, they ranked second and third in terms of area, respectively. Barley is the second most important crop in terms of the number of plots, but it is the fourth most important crop in terms of cultivated area (13 percent of the total area). The importance of the crops in terms of the area they are sown is similar to the national and agroecologic zone level average.

Table 3.20 Importance of crops in terms of area and number of plots they are cultivated on, 1999 meher season

Crop	Plots sown to		Area crop is sown	
	Number	Share	Hectares	Share
All crops	6,736	100	1,930.5	100
White teff	642	9.5	271.7	14.1
Black and mixed teff	372	5.5	190.9	9.9
Barley	759	11.3	251.6	13
Enset	675	10	64.2	3.3
Maize	664	9.9	290.1	15
Wheat	642	9.5	255.4	13.2
Coffee	623	9.3	62.4	3.2
Sorghum	319	4.7	94	4.9
Horse Beans	314	4.7	86.2	4.5
Chat	266	4	27.6	1.4
Sweet Potatoes	123	1.8	19.4	1
Chick peas	95	1.4	28.9	1.5
Cow Peas	89	1.3	23.7	1.2
Adenguare	61	0.9	8	0.4
Haricot bean	65	1	33.8	1.8

Source: ERHS round 5.

Enset is an important crop in the densely populated South Western part of the country. Although enset was only the seventh most important crop by area (3.3 percent of the cultivated area) it was the fourth most important crop in terms of number of plots, which is emblematic of the severity of land fragmentation, especially in the densely populated part of the country. Each of the surveys, including the 1999 survey, was intended to cover all agroclimatic regions and cultivation practices in the country. Enset is cultivated in six woredas by 29 percent of the 1,681 households. The number of plots cultivated in these regions represented 37 percent of the 6,712 of plots cultivated by the sample households, and overall each plot averaged about 0.15 hectares. However, the average size of enset farms was only about 0.1 hectare. Moreover, the extent of land fragmentation observed in these regions is indicative of the future scenario in other parts of the country. In addition, about 56 percent of the farmers surveyed in 1999 meher season reported deterioration in the fertility of the land they were cultivating. According to 43 percent of these farmers, continuous cultivation was the most important reason for the decline in fertility, while 39 percent of them reported that erosion was the principal cause. The absence of crop rotation and overgrazing also contributed to a decline in fertility.

The rain distribution during the 1999 meher season was excellent for only 8.8 percent of the 6,736 plots, while 28 percent of the plots had poor or no rain. More than 80 percent of the plots had average or below average rainfall while the distribution of rain with in the season was even worse (Table 3.21). In addition, rain started on time only on 64 percent of the plots, and 32 percent faced difficulties because of late rains. Moreover, 26 percent of the farmers had low production due to too little rain and 14 percent due to rains that stopped too early.

Given these challenging growing conditions, and most notably the frequent droughts that afflict the country, one may expect mechanisms to cope with low and highly variable rainfall would be widespread. However, only 187 or 2.8 percent of the 6,736 plots were irrigated in the 1999 meher season. Moreover, those plots were not fully irrigated or were not irrigated for the entire season. About 38.5 percent of the irrigated plots were sufficiently irrigated while more than 40 percent of them were provided with one-half or less of the necessary water.

The production of 250 households (15 percent of the sample) was adversely affected because they neither had oxen nor were able to rent or borrow animals. Among the 1,193 households, for which data on oxen ownership was available, 19 percent or 232 households had no oxen; 32 percent had only a single ox, while 49 percent owned two or more oxen. One-way households coped with shortage of draught animals was to borrow

Table 3.21 Amount and pattern of rainfall distribution in 1999.

Crop	Total rainfall						Distribution of Rainfall					
	Excellent	Good	Shortage	Cannot recall	Missing	Total	Excellent	Good	Poor	Cannot recall	Missing	Total
White teff												
Number of plots	226	313	93	1	9	642	49	325	253	6	9	644
Percent	35.1	48.6	14.4	0.2	1.7	100	7.6	50.5	39.3	0.9	1.7	100
Black and mixed teff												
Number of plots	43	187	130	-	12	372	28	190	142	-	12	372
Percent	11.6	50.3	34.9	-	3.2	100	7.5	51.1	38.2	-	3.2	100
Barley												
Number of plots	146	472	128	4	9	759	108	491	146	5	9	760
Percent	19.2	62.1	16.8	0.5	1.3	100	14.2	64.6	19.2	0.7	1.3	100
Wheat												
Number of plots	118	373	134	3	14	642	62	400	163	3	14	642
Percent	18.2	57.4	20.6	0.5	3.4	100	9.5	61.5	25.1	0.5	3.4	100
Maize												
Number of plots	74	289	291	-	10	664	43	269	339	3	10	664
Percent	11.1	43.5	43.8	-	1.7	100	6.5	40.5	51	0.5	1.7	100
Sorghum												
Number of plots	24	187	105	1	2	319	16	162	139	-	2	319
Percent	7.5	58.6	32.9	0.3	0.6	100	5	50.8	43.6	-	0.6	100
Coffee												
Number of plots	95	472	50	2	4	623	46	495	69	9	4	623
Percent	15.2	75.6	8	0.3	0.8	100	7.4	79.3	11.1	1.4	0.8	100
Enset												
Number of plots	109	509	53	2	4	675	49	531	83	10	4	675
Percent	16.1	75	7.8	0.3	0.6	100	7.2	78.2	12.2	1.5	0.9	100

Source: ERHS round 5.

or exchange oxen in return for ploughing services provided by their own animals. However, a household should own at least one animal to enter into such an arrangement. About 900 farmers used this arrangement, which is locally known as “mekenago.” Another means by which farmers can overcome this problem is to rent animals from households that own more oxen than they currently using. One hundred seven households (6 percent of the sample) rented oxen at either a daily or seasonal rate.

Modern Input Use, Extension Package Adoption, and Soil Conservation

A total of 3,382 plots were fertilized with either Urea or DAP. Out of the 2,196 plots fertilized with DAP 497 or about 23 percent were sown to white teff while 9.7 percent were sown to black and mixed teff; that is, the proportion of fertilized plots under teff was greater than proportion of area allocated for its production. Wheat was another important cereal, with 57 percent of the plots sown to wheat fertilized with DAP and 35 percent with Urea (although these ratios are not mutually exclusive in that a plot can be fertilized with both types of fertilizers). Out of the 664 plots sown to maize 51 percent were fertilized with DAP while 38 percent were fertilized with Urea. Coffee and enset were crops that received little or no fertilizer.

Farmers were receptive to the advice and training of extension agents and learned from observing fellow farmers. Fifty one percent of DAP users reported that they decided to use the input following the advise of extension agents and development workers, as did 59 percent of Urea users. Advise from relatives and friends were important sources of information. Thirty two percent of DAP users and 23 of Urea users used the inputs following the advise of their relatives and friends.

Very few farmers used other modern inputs such as herbicides, fungicides, and high yielding varieties seed. Fewer than 3 of the 1,681 farmers used the services of a tractor, combine, harvester, thresher, or maize sheller. Only 7 of the surveyed farmers used high yielding white teff seeds, while more farmers use modern wheat and maize seed varieties.

The reported sources of information for those who used pesticides and high yielding seed varieties were extension agents, development workers, and family and friends. Those who used little or no modern inputs reported that the high cost of those inputs were the most limiting factor.

Only 435 or 6.5 percent of the 6,736 plots were cultivated using the recommended extension package. The area covered by these plots was about 9 percent of the total area; 205 households or 12 percent of the 1,681 households farmed these plots. The number of households that adopted the extension package has been increasing at faster rate in the first four years since 1995, while it has slowed down between 1998 and 1999. Between 1995 and 1999, average annual growth rate of the number of adopting farmers was 24 percent. There were cases where farmers stopped using the package at a given year after using it for one or more years. The four important reasons why farmers ceased using the package were a shortage of cash for a down payment, a shortage of land, a lack of knowledge of the inputs, or failure to repay past loans. The same reasons constrained most farmers that did not use the package at all. Among those farmers, 31 percent did not have the minimum amount of cash required to partly cover the purchase of the inputs, and 23 percent did not have enough land to use the package of inputs. Among this group of farmers only 10 percent did not adopt the package because it was not provided in their locality.

Exposure to extension agents and prior experience with using modern inputs increase the likelihood that a farmer would adopt the extension package as well as the chance of being elected to serve as a contact farmer. Among the 1,681 household heads included in this sample 115 served as model farmers during the Dergue/Socialist government before 1991. Among those farmers that adopted the package of inputs in 1995, 1996, 1997, 1998 and 1999 these model farmers represented 29, 26, 23, 20, and 20 percent, respectively. Moreover, out of a total of 129 farmers that SG 2000 and the Ministry of Agriculture used as contact farmers, 113 successfully adopted the package. Only 198 households that specified the number of times they were visited by extension agents. Of these, less than

17 percent were visited more than four times, 20 percent were visited once, 30 percent were visited twice, 18 percent were visited three or four times. While only 15 percent reported receiving no visit, I suspect that most of the 1,483 missing values for this variable represent households in this category.

There were 417 households that practiced soil conservation on their 1,193 plots for an average of 12 years. These households represented one quarter of the total number of households, while the share and size of plots subject to soil conservation was about 20 and 16 percent, respectively. Soil conservation helps not only to rehabilitate the fertility of eroded soil but also to retain soil fertility. However, households that practiced soil conservation seem to concentrate their practice on seriously degraded plots, as they do not follow the practices on all of their plots. This is also supported by the reasons provided by households for not practicing soil conservation on some of their plots. Among those farmers that did not practice soil conservation, 77 percent did not because their plots were not affected by soil erosion, 16 percent faced shortage of labor, while 3 percent doubted its benefit. Distinct from the use of other modern inputs, most farmers practice soil conservation measure using non-purchased inputs (principally their own household labor) and on their own initiative. Soil conservation on 750 of the 1,193 plots were self initiated, those on 134 plots were encouraged by neighbors, and those on 200 plots were attributed to the advice by extension agents. The reason for stressing the importance of soil conservation measures is that with the current rate at which the population is increasing and with farmers having limited ability to fallow land, soil conservation measures will be essential to sustaining the productive value of the land.

Yield Levels and Loss of Output

The reported yield of farmers surveyed in round five is given in Table 3.22. Comparing these 1999 yields with those reported in the 2001/2 meher season reveals that households in the 1999 survey generally had lower yields, although the rate of modern input use among these households had increased on average. The yield performance of subsistence farmers depends largely on weather and agroecological conditions. The average yield in 1999 of the seven most important crops was only 93 percent of corresponding 2001 yields. Considering the four most important crops: teff, barley, wheat and maize, yields in 1999 were only 89 percent of their corresponding 2001 levels. Recall our discussion in section 3.5.1 (and Table 3.22) that the value of production declined in 1999 after a steady increase since 1994.

Table 3.22 Average yield level of farmers included in 1999 Ethiopian Rural Household Survey

Crops	Round five survey: Number of plots	Round five survey: Average yield (KG/ha)	Average yield (KG/ha) from aggregate 2001 data[a]	Ratio of average yield in round five to aggregate yield in 2001
White teff	631	791	874	0.91
Black and mixed teff	358	602	NA	NA
Barley	747	874	1022	0.86
Wheat	632	1166	1362	0.86
Maize	643	1674	1813	0.92
Sorghum	313	1514	1324	1.14
Horse Beans	303	883	1204	0.73
Linseed	58	556	508	1.1

Source: ERHS round 5.

Notes: a. Source: Central Agricultural Census Commission (2003).
NA represents data not available.

On average, 28 farmers lost about 264 kilograms of white teff from 104 plots sown to this crop. The loss of black and mixed teff by 30 farmers from 71 of plots sown to this crop was less severe at an average of 148 kilograms. Aggregate estimated maize loss were the largest as 157 farmers lost an average of 190 kilograms from their 289 plots; that is, 30,000 kilograms of maize was lost to damages. The only cereal with an average of less than a hundred kilograms of loss was barley. On average 80 farmers lost 48 kilograms from their 139 plots while 38 farmers lost an estimated average of 257 kilograms of wheat.

As discussed above, insufficient and untimely rains are among the reasons for such damages. Rain during harvest, wind and storm, hail, and flood and water logging represent only little problem. The worst damages were inflicted by plant diseases, insects, weeds and birds, wild animals, and by livestock (eating and trampling). While the data provide information on the kind of animals and the diseases that caused the damages, the general point is that there is some output that could be saved by reducing crop losses.

4. SOURCES OF INEFFICIENCY AND GROWTH IN AGRICULTURAL OUTPUT IN SUBSISTENCE AGRICULTURE: A STOCHASTIC FRONTIER ANALYSIS

4.1 Introduction

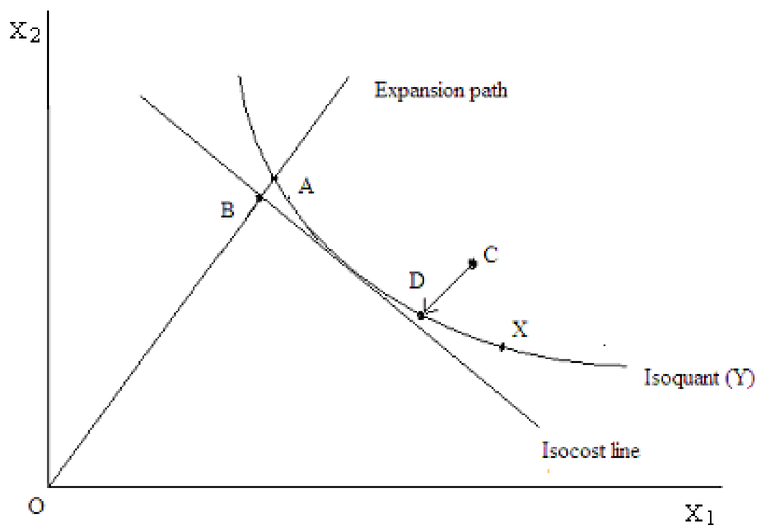
Studying the sources of increased production, and examining the extent and sources of measured production inefficiencies can reveal options for ameliorating the bleak conditions confronting Ethiopian agriculture illustrated in the previous chapter. To do this I will apply stochastic frontier analysis (SFA) methods to panel data from the various Ethiopian Rural Household Survey (ERHS).

Data envelopment analysis (DEA) and SFA approaches have often been used to measure firm-level technical efficiency. In addition to accounting for the role played by measured inputs in contributing to increased production under certain circumstances SFA analysis can also be used to estimate the magnitude and sources of farm-level inefficiency. In section 4.1.1 I provide alternative definitions of the concept of efficiency, then briefly review the literature and operational methods of data envelopment analysis approaches in section 4.1.2. This literature review will canvass the empirical options used to measure efficiency and to justify the approach I follow in this study. In section 4.2 I review the literature on SFA and describe the model used in this study.

4.1.1 Conceptual Background

A firm or farm household that is both allocatively and technically efficient is considered to be efficient. Farrell (1957) defined allocative efficiency of a farm household, or in his words “price efficiency,” of a two input (X_1, X_2), one output (Y_1) household as one which the ratio of the distance from the origin to the point on an isocost line to the distance from the origin to the isoquant, for points that lie on the same expansion path. An isoquant describes the combination of inputs that produce a given amount of output, while an isocost line represents different combinations of inputs that incur a given cost. In figure 4.1, Farrell's measure of allocative efficiency of a firm operating at point A is given by the ratio OB/OA. If the ratio equals 1 then the firm is allocatively efficient while if the ratio is less than 1 the firm is not allocatively efficient.

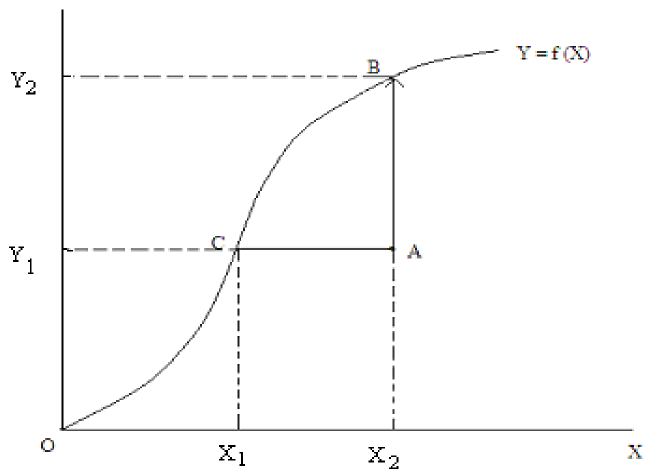
Figure 4.1 The input, isoquant, isocost, and expansion path



Source: Modified from Farrell (1957).

Koopmans (1957) defined a point in production space as "technically efficient" whenever an increase in the net output of one good can be achieved only at the cost of a decrease in the net output of another good. Kumbhakar and Lovell (2000) cast Koopmans' definition into input and output oriented notions of technical efficiency. Accordingly, an input vector ***x*** that is an element in the input requirement set of ***y*,** such as point ***x*** in Figure 4.1 above, is technically efficient if there does not exist any other vector ***x'*** that is less than or equal to ***x*.** This is the case if every element in ***x*** is less than or equal to the corresponding element in ***x'*.** Moreover, an output vector ***y*** that is an element in the production possibility set of an input vector ***x*** is technically efficient if there does not exist any other vector ***y'*** that is greater than or equal to ***y***. Under conditions of constant returns to scale and assuming that the efficient production function is known, Farrell (1957) defined technical efficiency of a firm as the ratio of the amount of aggregate input used by a technically efficient firm to the amount actually used by the firm, to produce a given level of output. In figure 4.2 below, assuming that the firm is using a single input ***x*** to produce a single output ***y***, and that firm A is operating at point A while the efficient firm is operating at point C, Farrell's measure of technical efficiency of firm A is given by the ratio OX1/OX2.

Figure 4.2 Production function of a firm using input **X** to produce **Y**



This measure of technical efficiency takes a value of 1 for a technically efficient firm and approaches zero as firms become less technically efficient, or as firms use increasingly larger amount of inputs to produce the same level of output. This definition of technical efficiency will have an important implication on the way the DEA and SFA estimation procedures are formulated.

This work studies technical efficiency. Perhaps the overriding reason for pursuing this direction is that information on the prices of all of the factors of production that are included in the Ethiopian Rural Household Survey data are unavailable, the other reason is provided by Farrell (1957), in which he shows that price efficiency is very sensitive to the introduction of new observations and to errors in estimating factor prices than is technical efficiency; making the measure unstable. In Figure 4.1 price efficiency of the firm operating at point A was given by the ratio OA/OB. This ratio depends on the slopes of the isocost line and the isoquant. Since the isocost line depends on relative prices of the inputs used in production, any error in estimating these prices affects the slope of the isocost line. The isoquant for producing a given amount of measured output (Y) is made up of a continuum of firms that produce at those points. The introduction of new firms may affect the slope of the isoquant and the measure of price efficiency if they operate around point A, making the measured price efficiency unstable. However, Farrel concedes that, "in a particular case where many observations and accurate price information were available, [this measure] might be quite reliable (Farrell 1957, p. 262).

4.1.2 Data Envelopment Analysis

Efficiency measures that employ data envelopment analysis (DEA) have their roots in the works of Debreu (1951), Koopmans (1957), Farrell (1957), Charnes and Cooper (1957), and Shephard (1970). These approaches provide measures of farm-level efficiency and the measures are relative because the efficiency level of each farm is compared against the most efficient farm that operates under similar circumstances, using the same production technology. These measures use input and output distance functions that were central to Koopmans' and Farrell's definition of technical efficiency. Following Fare, Grosskopf, and Lovell (1985) I define input and output distance functions by assuming a production technology of a farm household, T, which is given by $T \subseteq R_+^N \times R_+^M$, where T is defined as

$$T^h = \{(x^h, y^h) : x^h \text{ can produce } y^h\} \qquad (4.1)$$

where R_+^N and R_+^M are the positive orthant of N and M dimensional real numbers, respectively, $x^h \in R_+^N$ is a vector of N inputs, $y^h \in R_+^M$ is a vector of M outputs, and $h \in \{1,2,...,H\}$ represents household h.

Then Shephard's output distance function is given by

$$D_o^h(\mathrm{x}^h, \mathrm{y}^h) = \inf\{\theta : (x^h, y^h/\theta) \in T\} \tag{4.2}$$

where D_o^h stands for output distance function, and $0 < \theta \leq 1$. Inf represents the infimum function, which calculates the minimum value of the function in the curly brackets.

The output distance function given by Equation (4.2) is defined under four assumptions. Let us first define the set of feasible or producible outputs as $P(x)$. That is, $P(x) = \{y : (x, y) \in T\}$. Then

Assumption 1. $0_M \in P(x)$ for all x in R_+^N (Inaction is possible: given any input vector it is always possible to produce nothing).

Assumption 2. For all (x, y) in $R_+^N \times R_+^M$, if $y \in P(x)$ and $0 < \theta \leq 1$ then $\theta y \in P(x)$. (Weak disposability of outputs: If x can produce y then x can produce any proportional reduction of y).

Assumption 3. For all $x^h \in R_+^N$, $P(x)$ is a bounded set. (Finite inputs can only produce finite outputs).

Assumption 4. For all $x^h \in R_+^N$, $P(x)$ is a closed set.

We can see the logic of the output distance function in Figure 4.2. The value of the output distance function of a farm operating at point A, is a value that translates the output of farm household A, Y_1, to the maximum quantity possible, Y_2, from using the same amount of input, X_2. In this case of single output, given that $Y_2 = Y_1/\theta$, θ can be calculated as $\theta = Y_1/Y_2$. In the case of farms producing multiple outputs using multiple inputs, the calculated value of θ indicates the extent to which the production of each of the items can be increased equiproportionally, without increasing input use. Specifically θ^{-1} represents the percentage increase in output that can be achieved if production was to be brought onto the production frontier experienced by the most efficient farms. The calculated value of the output distance function of those farms that operate on the production frontier is 1, while those farms operating under the frontier will have a value that is less than one.

Similarly an input distance function is defined as[38]

$$D_I^h(\mathrm{x}^h, \mathrm{y}^h) = \sup\{\beta : (x^h / \beta, y^h) \in T\} \qquad (4.3)$$

where $\beta \geq 1$ and D_I^h stands for input distance function. Sup represents the supremum function, which calculates the maximum value of the function in the curly brackets. We can see the logic behind this definition in Figure 4.1. The value of the input distance function of a farm household operating at point C is one that translates the input use level of the farm to the minimum possible level while still producing a given amount of output specified by the isoquant. In the case of multi-input, multi-output firms, the calculated value of the input distance function, β, represents the equiproportionate decrease in the use of the inputs that the farm can achieve without reducing its production. Farms that operate on their isoquant have a value of 1 for the input distance function while those that operate above the isoquant have a value greater than 1.

The definitions of the distance functions given above presuppose that we know the frontier, so that we can use those farms at the frontier or their convex combination as a yardstick against which to measure the level of technical efficiency of the ones that operate under the frontier. But in non-parametric data analysis this frontier is unobservable; we only have a set of data points from which to construct a representative frontier. Data envelopment analysis methods are then used to compare each decision-making unit (DMU) with a convex combination of the producers on the frontier. This approach considers the frontier that is constructed as the efficient level of production without allowing for measurement and other stochastic errors. This fact that DEA does

[38]The input distance function assumes a set of input disposability and boundary conditions similar to the output distance function. See Fare and Primont (1995) for easily accessible explanation of the assumptions and properties of input and output distance functions.

not recognize such idiosyncratic errors is an important reason to choose SFA over DEA. Fare, Grosskopf and Lovell (1985) formulate the following linear programming problem that solves for the optimal input or output distance function for each farm.

Following the notations above, let there be n = 1,2,…,N inputs, m = 1,2,…,M outputs. Let the amount of input n used by the farmer h be given by x_{nh}, and let the amount of output of type m that this farmer produced be given by y_{mh}, then the input-oriented distance function is calculated by solving the linear programming problem

$$\mathrm{B}^* = \min \mathrm{B} \tag{4.4}$$

Such that,

$$\mathrm{B}x_{nh} - \sum_{h=1}^{H} \lambda_h x_{nh} \geq 0, \quad n \in \{1,2,...,N\}$$

$$y_{mh} - \sum_{h=1}^{H} \lambda_h y_{mh} \leq 0, \quad m \in \{1,2,...,M\}$$

$$\lambda_h \geq 0, \quad h \in \{1,2,...,H\}$$

This problem seeks a value of B that optimizes the reduction in the amount of input used by the farmer under consideration, farmer h, while still keeping input use above or equal to the convex combination of the inputs used by the efficient firms. The amount of input use by farm h should lie above or on the isoquant that is made up of the convex combination of inputs used by the most efficient DMUs, which sometimes are called virtual producers. Note that B is the inverse of the input distance function given in equation (4.3).

The output-oriented distance function is solved from the linear programming problem

$$\Theta^* = \max \Theta \tag{4.5}$$

Such that,

$$\Theta y_{mh} - \sum_{h=1}^{H} \lambda_h y_{mh} \leq 0, \; m \in \{1,2,...,M\}$$

$$x_{nh} - \sum_{h=1}^{H} \lambda_h x_{nh} \geq 0, \; n \in \{1,2,...,N\}$$

$$\lambda_h \geq 0, \; h \in \{1,2,...,H\}$$

The linear programming problem above calculates a value of Θ that maximizes the increase in the production of farmer h while still keeping the production within the frontier created by the virtual producers. The second constraint restricts farmer h to use at least as much input as the one that is used by the virtual producers.

In the following section I discuss the theory behind the methodology used in this study, namely, the stochastic frontier approach (SFA). Then I discuss the theoretical and econometric models, which will be used to study the level of efficiency and sources of productivity growth in peasant households in Ethiopia.

4.2 Stochastic Production Frontier Analysis

4.2.1 Background

Most microeconomic analyses estimate production functions under the assumption that producers are rational profit maximizers operating on their production frontiers. However, Aigner, Lovell, and Schimidt (1977), Meeusen and Van den Broeck (1977), Farrell (1957), and Battese and Coelli (1995) support the view that producers differ in the amount of measured output they produce from a given bundle of measured input, or, alternatively, in the amount of inputs they require to produce a given amount of output. Differences in efficiency could result from difference in the managerial ability of farmers, or factors that are impossible or hard to enumerate but affect the amount farmers produce. Part of the measured deviations from "optimal" efficiency could also be explained by measurement error and the omission of inputs used or outputs produced in the production activity, the types of which are discussed at the end of this chapter. Methods that do not recognize the existence of these empirical problems and assume that farmers are the same in their managerial or farming abilities, use a variant of the classical linear regression model in which error terms are assumed to be distributed symmetrically, with zero mean. Error terms are meant to capture random differences that cannot be explained by variables included in the models. Such models as the classical linear regression model essentially disregard the difference in efficiency between producers, and consider such difference a result of random or idiosyncratic noise, thereby falling into the error of misspecification of the production function. In addition to this, farmers may fail to use inputs in a cost minimizing way and thus could also be allocatively inefficient.

Given that not all producers are equally technically or allocatively efficient we need to specify production functions in a way that acknowledges efficiency differences and errors. Stochastic production frontiers (SFA) accomplish this task partly by accounting for differences in efficiency among farmers. The use of production frontiers differs from ordinary least squares methods in its use of "composed error terms," rather than assuming symmetrically distributed, zero mean error terms as analysts do when using conventional least squares approaches.

Composed error terms are composed of two error terms: a symmetric error term that is typically meant to represent idiosyncratic disturbances in the production environment that can affect output positively or negatively. These disturbances mean that producers may fall above or below the frontier as they are assumed to be symmetrically distributed with zero mean. A distinctive feature of SFA is the second component of the composed error. These disturbances are assumed to take only zero or positive values; those producers with positive values lie below the efficiency frontier while those with zero values are efficient farmers that lie on the efficiency frontier. This part of the error term is taken to represent the level of inefficiency, and as such it measures the departure of each producer from an efficiency frontier. Since the specification of a stochastic production frontier takes the difference of the first error component from the second, (see equation 4.7 below) composed error terms are always non-zero – specifically they are negatively skewed. Given this property of error terms one can use residuals from ordinary least squares estimation of a well specified production function to check for negative skewness using a test statistic developed by Schmidt and Lin (1984) and Coelli (1995); whereby a result of negative skewness is considered evidence of the existence of inefficiency. In the results section I present the result of such a test.

Farrell's work served as a basis for Aigner and Chu's (1968) work that estimated deterministic production functions recognizing the existence of differences in inefficiency between firms in a given industry and that "…the industry production function is conceptually a frontier of potential attainment for a given input combinations (p. 826)." The mathematical programming method developed by Aigner and Chu (1968) served as a precursor for contemporary SFA studies. In this deterministic approach to production frontiers the authors recognize the existence of differences in inefficiency between decision-making units, although these units share a common deterministic production function. They assume a production function $x_0 = Ax_1^{\alpha} x_2^{\beta} u$, where x_0 is output, x_1 and x_2 are inputs, α and β are parameters, and u is random term that is taken to measure inefficiency. The authors suggest two methods to estimate the proportionate deviation in production of each producer from the maximum feasible output, which is then used to estimate the producer's technical efficiency. One method solves the problem

$$\text{Min} \sum_h e_h \qquad (4.6)$$

Such that, $\ln A + \alpha \ln x_1 + \beta \ln x_2 \geq \ln x_0$, h=1, 2, …H

$\alpha, \beta \geq 0$

where $e_i = \ln x_0 - \ln A - \alpha \ln x_1 - \beta \ln x_2$ is the deviation of output of firm h from the potential maximum and H is the total number of firms (households) in the industry. The second method minimizes the squared sum of the deviations subject to the first constraint. Kumbhakar and Lovell (2000) argue that these methods have a major drawback as the parameters are derived as solutions to a linear programming problem and are not estimated using regression techniques. This makes it difficult to draw any statistical inferences about the estimated parameters; the authors then discuss some of the remedies in the literature to address these problems.

Winsten (1957) suggested a method to improve the efficiency frontier that Farrell constructed from firms that are achieving the highest production, which was then used to measure the level of inefficiency of others that are with in the frontier. Winsten noted, "It would also be interesting to know whether in practice this efficient production function [that Farrell estimated] turned out to be parallel to the average production function, and whether it might not be possible to fit a line to the averages, and then shift it parallel to itself to estimate the efficient production function (p. 283)." The procedure that followed this suggestion came to be known as corrected ordinary least squares (COLS). Kumbhakar and Lovell (2000) discuss that this method involves first estimating the equation $\ln x_0 = \ln A + \alpha \ln x_1 + \beta \ln x_2 + e$ using ordinary least squares, which provides consistent and unbiased estimates of the slope parameters and a consistent but biased estimate of the intercept parameter $\ln \hat{A}$. The second step involves adjusting or correcting the biased intercept term to ensure that the estimated production function bounds the data from above, so the adjusted intercept term is: $\ln \hat{A}_h^* = \ln \hat{A}_h + \max_h\{\hat{e}_h\}$, where $\hat{e}_h$ are OLS residuals. These residuals are corrected as: $-\hat{e}_h^* = \hat{e}_h - \max_h\{\hat{e}_h\}$ to provide a measure of efficiency of $TE_h = \exp\{-\hat{e}_h^*\}$, where TE_h stands for technical efficiency of farmer h. The corrected residuals are negative with at least one being zero. Kumbhakar and Lovell (2000) criticize this approach for limiting the best practice technology or the frontier to have the same structure as the central tendency technology obtained by OLS. Note that the adjusted frontier is a parallel shift of the least square estimated production function. A similar procedure that was suggested and applied by Afriat (1972) and Richmond (1974), adjusted both the intercept term and the error terms by the mean value of the error terms rather than by the maximum value. This approach is called modified ordinary least squares (MOLS). In addition to the problem identified using the COLS the MOLS method suffers from a additional problem in that some observations may fall above the frontier making it hard to explain what these observations represent given the basic premise that a frontier is an outer bound of the observations.

Based on these concerns Aigner, Lovell, and Schimidt (1977) and Meeusen and Van den Broeck (1977) proposed a stochastic frontier approach. In this study I will employ a variant of this method, first suggested by Pitt and Lee (1981) among others. In implementing the method I closely follow Battese and Coelli's (1995) approach.

4.2.2 Model of Stochastic Production Frontier

Suppose the stochastic production frontier associated with farmer i at period t is given by

$$Y_{ht} = f(X_{ht}, \beta) * \exp(V_{ht} - U_{ht}) \qquad (4.7)$$

where $h \in (1,2,...,H)$ is an index for farm household h and $t \in (1,2,...,T)$ represents time period t. Y_{ht} is output of farmer h at time period t while X_{ht} is a (1 × k) vector of inputs of farmer h at time period t (and depending on the specification of $f(X_{ht}, \beta)$, interaction terms of the inputs). β is a (k×1) vector of unknown parameters to be estimated. V_{ht} and U_{ht} are the idiosyncratic and inefficiency components of the "composed error term" of farmer h at time period t, discussed earlier. We make the following three assumptions about these error terms

i) V_{ht} are identically and independently normally distributed with mean zero and standard deviation σ_v^2, that is V_{ht} ~N($0, \sigma_v^2$).

ii) U_{ht} are independently distributed non-negative truncation of a normally distributed random variable with mean $Z_{ht}\delta$ and standard deviation σ_u^2 or U_{ht} ~N($Z_{ht}\delta, \sigma_u^2$). Where Z_{ht} is a (1 × m) vector of household and region specific variables that we assume affect efficiency while δ is an (m × 1) vector of unknown parameters of the inefficiency equation.

iii) V_{ht} and U_{ht} are distributed independently of each other and are independently distributed of the X_{ht}.

The variables of the stochastic production frontier, equation (4.7), are physical or values of input used in production and outputs produced, and the frontier represents the functional relationship between inputs and output/s. The deterministic component of the frontier, $f(X_{ht}, \beta)$, is frequently specified either in Cobb-Douglas or log-linear forms. In this thesis I use the Cobb-Douglas specification for the baseline analysis, but present parameter estimates for other specifications in sub-section 4.4.2 for comparative purposes.

Given a stochastic production frontier that is specified by equation (4.7), the level of technical efficiency (TE_{ht}) of each farm household h at period t is given by

$$TE_{ht} = \frac{Y_{ht}}{f(X_{ht}, \beta) * \exp(V_{ht})}$$

$$TE_{ht} = \exp(-U_{ht}) \qquad (4.8)$$

Since U_{ht} are a non-negative truncation of a normally distributed random variable, TE_{ht} can take a maximum value of one, for $U_{ht} = 0$. As U_{ht} increases in value TE_{ht} declines. Given this distribution, higher U_{ht} occur with decreasing probability, which means increased inefficiency occurs with less probability. The specification implicitly assumes that the efficiency scores of each farm household can vary in each period, which takes in to account improvements in efficiency and possible rearrangement of efficiency scores among households across time periods. The definition of technical efficiency given above can be justified by the fact that if a farm household's actual production level, Y_{ht}, is less than the maximum achievable production level, $f(X_{ht}, \beta) * \exp(V_{ht})$ - which admits the existence of only idiosyncratic differences - and assuming that there are no measurement errors, then there is some inefficiency on the part of the farmer. Moreover this inefficiency is greater the lower Y_{ht} is from $f(X_{ht}, \beta) * \exp(V_{ht})$, or the higher is U_{ht}.

The inefficiency effects, U_{ht}, as well as the symmetric error terms, V_{ht}, may carry the effects of errors of measurement in both the explanatory as well as the explained variables. Although a joint effort had been made with researchers at IFPRI to increase the quality of the data and tremendous improvements have been made, I concede that some measured input uses may have been omitted, such as irrigation. In the results and discussions section I will argue that the composed error term in this study is principally a measure of inefficiency and not idiosyncratic errors, in this theoretical section, I assume that the idiosyncratic errors are randomized across observations and periods.

The technical inefficiency effects, U_{ht}, are assumed to be a function of farm household and region specific variables, Z_{ht}, and a set of parameter values, δ, to be estimated along with the production function parameters. Huang and Liu (1994) argue that either household or region-specific characteristics affect different inputs differently and specify an inefficiency equation with interaction terms of input variables and farm or region-specific variables included in the Z_{ht}. They find this approach to be a better specification than the equation with only household and region specific variables included in the Z_{ht}.

The inefficiency equation is specified as

$$U_{ht} = Z_{ht}\delta + W_{ht} \qquad (4.9)$$

where W_{ht} is a random variable distributed with mean value of zero and variance σ_w^2 that is, $W_{ht} \sim \mathrm{N}(0, \sigma_w^2)$. The random variable U_{ht} is defined by the truncation of the normal distribution with the point of truncation given by $-Z_{ht}\delta$. Since $U_{ht} = Z_{ht}\delta + W_{ht} \geq 0$ it should hold that $W_{ht} \geq -Z_{ht}\delta$ that is W_{ht} is truncated from below. The assumption of truncated normal distribution for the U_{ht}'s is an approach that was suggested by Stevenson (1980) that generalizes the half-normal distribution assumption which was presented in the work of Aigner, Lovell, and Schimidt (1977). In the half normal distribution U_{ht} are assumed to be the positive half of a normally distributed variable with mean zero ($U_{ht} \sim N^{+}(0, \sigma_u^2)$). Kumbhakar and Lovell (2000) state that individual efficiency scores as well as the composition of the top and bottom efficiency score deciles are not affected by the distributional assumptions of the inefficiency component, U_{ht}, and suggest the use of relatively simple distributions such as a half normal or an exponential distribution. In this study I opt to use the more flexible truncated normal distribution.

The truncated normal distribution for U_{ht} is given by

$$g_u(U_{ht}) = \frac{1}{\sqrt{2\pi}\sigma_u \Phi(Z_{ht}\delta / \sigma_u)} \exp\left\{-\frac{(U_{ht} - Z_{ht}\delta)^2}{2\sigma_u^2}\right\}, \quad U_{ht} \geq 0 \qquad (4.10)$$

where $\Phi(.)$ is the standard normal cumulative distribution. Thus $g_u(U_{ht})$ is the density function of a normally distributed random variable with mean $Z_{ht}\delta$ truncated below at zero.

The density function of the random variable V_{ht} is given by

$$g_v(V_{ht}) = \frac{1}{\sqrt{2\pi}\sigma_v} \exp\left\{-\frac{V_{ht}^2}{2\sigma_v^2}\right\}, \quad V_{ht} \in (-\infty, \infty) \qquad (4.11)$$

To avoid clutter, I omit the subscripts h and t from now on. Given V and U are assumed to be distributed independently their joint distribution is given as:

$$g_{uv}(U,V) = \frac{1}{2\pi\sigma_u\sigma_v\Phi(Z\delta/\sigma_u)}\exp\left\{-\frac{(U-Z\delta)^2}{2\sigma_u^2}-\frac{V^2}{2\sigma_v^2}\right\},\ U \geq 0 \tag{4.12}$$

Let's define the composite error term as $\varepsilon_{ht} = V_{ht} - U_{ht} = Y_{ht} - f(X_{ht}, \beta)$; again leaving out h and t, the joint distribution of ε and U is given by

$$f(U,\varepsilon) = \frac{1}{2\pi\sigma_u\sigma_v\Phi(Z\delta/\sigma_u)}\exp\left\{-\frac{(U-Z\delta)^2}{2\sigma_u^2}-\frac{(U+\varepsilon)^2}{2\sigma_v^2}\right\} \tag{4.13}$$

The marginal density function of ε is given by

$$g_\varepsilon(\varepsilon) = \int_0^\infty f(U,\varepsilon)dU$$
$$g_\varepsilon(\varepsilon) = \frac{1}{\sqrt{2\pi}(\sigma_v^2+\sigma_u^2)^{1/2}\left[\Phi(Z\delta/\sigma_u)/\Phi(\mu^*/\sigma_*)\right]}\exp\left\{-\frac{(U+\varepsilon)^2}{2(\sigma_v^2+\sigma_u^2)}\right\} \tag{4.14}$$

Where by $\mu^* = (\sigma_v^2 Z\delta - \sigma_u^2\varepsilon)/(\sigma_v^2+\sigma_u^2)$ and $\sigma_*^2 = (\sigma_v^2 \times \sigma_u^2)/(\sigma_v^2+\sigma_u^2)$. We can use this last equation to express the density function of Y_{ht} as

$$g_y(Y_{ht}) = \frac{1}{\sqrt{2\pi}(\sigma_v^2+\sigma_u^2)^{1/2}\left[\Phi(\tilde{\mu}_{ht})/\Phi(\tilde{\mu}_{ht}^*)\right]}\exp\left\{-\frac{(Y_{ht}-f(X_{ht},\beta)+Z_{ht}\delta)^2}{2(\sigma_v^2+\sigma_u^2)}\right\} \tag{4.15}$$

whereby $\tilde{\mu}_{ht} = Z_{ht}\delta/\sigma_u$, $\tilde{\mu}_{ht}^* = \mu_{ht}^*/\sigma_*$, and $\mu_{ht}^* = [\sigma_v^2 Z_{ht}\delta - \sigma_u^2(Y_{ht} - f(X_{ht},\beta))]/(\sigma_v^2+\sigma_u^2)$; note that the notations μ^* and μ_{ht}^* are the same except the later one adds the subscripts h and t.

Let us define: $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$. This last reparameterization of σ_v^2 and σ_u^2 to σ^2 and γ is convenient. Note that $\gamma \in (0,1)$; if $\gamma \to 0$ then either $\sigma_u^2 \to 0$ or $\sigma_v^2 \to \infty$ which results if the symmetric disturbance term V_{ht} dominates the truncated efficiency component U_{ht} which in turn indicates that the idiosyncratic error component dominates the inefficiency effects and that OLS estimation techniques are more appropriate than stochastic frontier analysis. As $\gamma \to 1$ either $\sigma_u^2 \to (\sigma_u^2 + \sigma_v^2)$ or $\sigma_v^2 \to 0$ which results if the variation in the inefficiency component explains the entire variation in ε_{ht} and that indicates that stochastic production frontier is the appropriate procedure.

Given the above reparameterizations and that we have observations for $t \in (1,2,...,T)$ and $h \in (1,2,...,H)$ the log likelihood equation is given by

$$L(\Theta, Y) = -\frac{1}{2}\left\{\left[\sum_{h=1}^{H}\sum_{t=1}^{T}\ln 2\pi + \ln\sigma^2\right] + \left[\sum_{h=1}^{H}\sum_{t=1}^{T}(Y_{ht} - f(X_{ht}, \beta) + Z_{ht}\delta)/\sigma^2\right] + \left[\ln\Phi(\tilde{\mu}_{ht}) - \ln(\tilde{\mu}_{ht}^{*})\right]\right\} \tag{4.16}$$

where $\Theta' = (\beta', \delta', \sigma_v^2, \sigma_u^2)'$ is the parameter set. First order derivatives of this last equation with respect to the parameter set provides an expression which when solved will result in the estimates for the parameters.[39]

4.3 Data Description and Empirical Model Specification

Data from the five rounds of the Ethiopian Rural Household Survey conducted in 1994, 1995, 1997, 1999, and 2004 are used in this analysis. Round three has 1,480 farm households with usable agricultural data, while the other rounds have fewer households. Pooling across all five rounds, 596 of a total of 7,082 observations were omitted. They were dropped because the lacked a positive entry for cultivated land, and it makes sense

[39] These expressions are provided in Appendix 3.A.

to analyze crop-farming efficiencies for a sample of households that report some cultivated land. In addition to variation in sample size among years, the data used to construct some of the variables also varied over the rounds. Notably, data on labor use were collected for different durations. In two rounds, labor use data were collected only for the 30 days preceding the interview while in three rounds the labor data pertain to the entire farming season. Given this inconsistency I opted to use a proxy for labor namely the number of household members 16 years of age and above.

4.3.1 Data Used in the Stochastic Production Frontier

The real value of output variable that is used as a regressand in this study is calculated from the various items produced by each household. While I justified this approach in chapter 2, such an approach is not uncommon in stochastic frontier analysis. In their pioneering work on the application of stochastic production frontier to panel data, Battese and Coelli (1993) used the value of output of Indian farmers as their left-hand side variable. Unlike the value of output, the input variables used in this analysis are measured in quantity terms. Area cultivated is in hectares, amount of fertilizer used is given in kilograms, labor is measured by a proxy variable (specifically the number of household members 16 years old and above), and hoes, ploughs, and oxen used for ploughing are each measured in stock or count terms. An index of land quality is devised using the two indicators of land quality: slope and nutrient status, as discussed in chapter 3 and averaged over the number of plots that the household cultivates. The amount of rain is measured in millimeters, while I used a dummy variable to distinguish between farmers that cultivated their land using the recommended extension package and those that did not. Table 4.1 summarizes the input and output data used in the analysis.

On a per household basis, the average real value of output, cultivated area, average number of household members 16 years of age and older, and average number of oxen used for ploughing were the highest in 1997. Average real value of output steadily increased from 1,144 birr in 1994 to 1,836 birr in 1997, declined from 1997 to 1999, then increased again between 1999 and 2004. Average cultivated area per household ranged from a low of 0.9 hectares in 1999 to a high of 1.9 hectares in 1997, which could partly explain the difference in average value of output per household between 1997 and 1999. Average fertilizer use per household ranged from 28 kilograms in 2004 to 50 kilograms in 1999. Only 20 percent of the farmers applied fertilizer in 2004, while 42 percent applied in 1999. Average land quality has been constantly falling over the period from 1994 through 2004. Average annual rainfall varied from 909 millimeters in 1994 to 1,070 millimeters in 1997. Each household used an average of 1 hoe and 1 plough during this period. About 12 percent of the surveyed farmers adopted the extension package in 1999 while the average rate of adoption was lower than 10 percent in all other periods.

Table 4.1 Mean values of input-output data used in stochastic production frontier

Variable	Year				
	1994	1995	1997	1999	2004
Real value of output (birr)	1,144	1,214	1,836	1,687	1,811
Cultivated area (hectares)	1.2	1.2	1.9	0.9	1
Household members 16 years or older (count)	3.3	3.3	3.9	3	2.7
Annual rain 12 months before survey (millimeters)	908.8	1008	1070	961.1	942.3
Fertilizer used (kilograms)	38	41.7	48.6	49.6	27.8
Number of oxen used for ploughing (count)	1.3	1.3	1.7	1.4	0.9
Average land quality (index[a])	2.5	2.4	2.1	2.2	2.2
Number of hoes owned (count)	0.8	0.9	0.9	1.3	1.1
Number of ploughs owned (count)	0.8	1.1	1.1	1.4	1.1
Participated in the extension package (1 if yes)	0.06	0.03	0.05	0.12	0.08

Source: Calculated from ERHS panel data. All table entries given on a per household basis. Each round contained different number of households. See Table 2.2 for number of households used in the analysis.

Note: a. The average land quality index is calculated by multiplying the two indices that assign a value of 1 if the slope is flat and similarly a value of 1 if the land is rich in its mineral content. Land that is best in its slope and mineral content gets a value of 1, ranging to a value of 9 for land of lowest quality.

4.3.2 Data Used in the Inefficiency Equation

This part of the stochastic frontier analysis strives to explain household level farming efficiency using household, peasant association, and agroecologic level characteristics. This is called an ‘inefficiency equation’ because the left hand variable is the efficiency deviation of each household at each period from the most efficient farm household/s that have an efficiency score of 1 during that period.

Data on age and sex of the head of the household is included in the inefficiency equation to determine if these factors contribute to differences in efficiency among farm households. Although the sample ages over time, in some households older heads die and are replaced by younger heads, leaving average ages unchanged. About 80 percent of the households were headed by males.

The education status of household heads was also included in the inefficiency equation and in the stochastic production frontier to see if human capital contributed to farming efficiency and output, respectively. The justification for using this variable is that education improves efficiency not only by enabling farmers to read materials that help improve the operation of their specific farming operations but also by changing their attitude towards the use of modern inputs. In addition, farmers with higher amount of human capital are expected to be more productive in general. Two categories were created from the data on the education status of household heads. Heads with education levels up to grade 3 were assigned a value of zero while those that above grade 3 were assigned a value of 1.[40] During the 1994 to 2004 period, on average about 17 percent of household heads had education level of grades 3 or above. I used household size in the inefficiency equation to proxy the contribution of younger members of the household during peak seasons and the reductions in inefficiency that could result from such contributions. In each of the years, on average, about 6 members lived in each household.

An interaction variable created by multiplying the number of plots cultivated and the size of cultivated land was included in the analysis to determine if fragmented land holdings play a role in affecting household farming efficiency. I have two reasons for including this interaction term. For a given size of cultivated land the fewer the number of plots, the

[40] I thank John Hoddinott for suggesting this classification and providing the justification that household heads with education level of grades 3 and below will through time lose the education skills, as they usually do not have the chance to improve their skills. Results from this specification are similar with earlier estimates that used grade levels of household heads.

less distance the farmer is likely to travel to tend the plots, thus reducing measured inefficiency. On the other hand, plots that are sufficiently apart can reduce risks associated with severe but localized weather events and with low quality land. The data reveal an increase in the number of plots farmed over the years from 3.3 in 1994 to 4.5 in 2004, which results when new plots are allocated to households with increased family size.

Table 4.2 Mean values of household, peasant association, and agroecologic specific variables used in the inefficiency equation

Variable		Average value across survey Years
Type	Units	
Sex of head of household	0 if female, 1 if male	0.8
Age of head of household	Years	49.29
Education level of head	0 if illiterate, 1 if literate	0.17
Household size	Count	6.07
Number of plots cultivated	Count	4.09
Livestock units per household	Index[a]	2.89
Number of extension officers in PA	Count	0.75
Was crop damaged by drought	0 if no, 1 if yes	0.09
Mean elevation	Meters	2092.8
Distance to nearest health center	Kilometers	21.28
Distance to closest market	Kilometers	25.54
Distance to nearest PA center	Kilometers	24.36
Distance to nearest cooperative office	Kilometers	61.99

Source: Calculated from ERHS panel data

Note: a. livestock units is an index that is calculated by researchers at IFPRI, it converts farm animal ownership of a household into livestock units.

Area of cultivated land was divided by the number of household members 16 years and older, and was used in the analysis to assess the efficiency effect of variations in the cultivated land per working member of the household. Scaled livestock units as calculated by IFPRI researchers were also included in the analysis. This variable converts each type of farm animal owned by each household into livestock equivalent units. I used this variable as a proxy for wealth of a household as in most rural areas animals are considered a store of value and a ready means of acquiring cash in times of need. This affects farming efficiency because farm households with significant numbers of livestock units may have ready access to purchased inputs. The average value of this variable ranged between a low of 2.5 in 1995 to a high of 3.3 in 1997.

On average farmers traveled about 21 kilometers to acquire medical services, about 25 kilometers to the nearest market or peasant association center, while farmers' cooperatives offices were on average 61 kilometers away from where farm households lived. Given that farmers would be required to devote farming time and resources to acquire services provided by these facilities, these variables may have a measurable effect on farming efficiency. These variables might also reflect variation in the on-farm cost of purchased inputs. Farm households lived in villages located at altitude ranging from 977 to 3041 meters above sea level.[41] The altitude variable was included as one indicator of the climate of each of the surveyed regions along with dummy variables that were assigned for different agroclimatic zones. In 1994, drought adversely affected 29 percent of the surveyed farmers, compared with 17 percent in 1995. A dummy variable on drought was included in the analysis to account for adverse climatic factors that could lead to low efficiency of farm households. In the inefficiency equation I also included the number of agricultural extension agents in each of the peasant associations to assess the effect on farming efficiency of the number of agricultural extension staff in each of the regions. On average, there was less than a single extension agent per peasant association in all the years, the last two survey years of 1999 and 2004 had higher averages than the first three years of 1994, 1995, and 1997.

4.3.3 Empirical Model

Most prior attempts to estimate stochastic production frontiers use a linear or Cobb-Douglas specification for the functional form implicit in the expression $Y_{ht} = f(X_{ht}, \beta) * \exp(V_{ht} - U_{ht})$ given by equation (4.7) above. In this study I will focus mainly on the Cobb-Douglas specification, but in section 4.4.2 I will discuss results from

[41] I thank IFPRI researchers for calculating these geographic information and providing them for me to use in this study.

other specifications. I will follow standard prior practice in the specification of the inefficiency equation by assuming that household, village, and agroecologic zone-specific factors affect inefficiency linearly. Following Huang and Liu (1994) I will use an interaction variable of area cultivated with number of plots to capture the effect on faming efficiency of dispersed agricultural land per given area.

The empirical version of the stochastic production frontier using the semi-logarithmic form of the Cobb-Douglas specification is defined in equation (4.17). Note that area, labor, and mean annual rainfall are in logarithms while the remaining variables are not in logarithms. This specification was construed with an eye to two broad classes of variables; those without which farmers could not produce any output (specifically land, labor, and rain/water) and those that are not essential for production (specifically fertilizer, oxen, low quality land, extension package, hoes, and ploughs). Given this particular specification, use levels of the first three variables must be greater than zero while a household may still produce absent the non-essential inputs.

$$\begin{aligned}\ln Y_{ht} = {} & \beta_0 + \beta_1 \ln Area_{ht} + \beta_2 \ln Over16members_{ht} + \beta_3 Education_{ht} + \beta_4 \ln annualrain_{ht} + \\ & \beta_5 FertUse_{ht} + \beta_6 Oxen_{ht} + \beta_7 Avlandquality_{ht} + \beta_8 hoe_{ht} + \beta_9 Plough_{ht} + \beta_{10} Partnep_{ht} + \\ & \beta_{11} 1995dummy_h + ... + \beta_{14} 2004dummy_h + \beta_{15} CentralHL_{ht} + ... + \beta_{18} Enset_{ht} + \\ & V_{ht} - U_{ht}\end{aligned} \tag{4.17}$$

where $t \in (1,2,4,6,11)$ is the period for which data are available for the 11 year period extending from 1994 through 2004, and where $h \in (1,2,3,...,1480)$ represents farmer h. β_j, j = 1, 2, …,18 are coefficients of the production function to be estimated. The variables are defined in Table 4.3.

As explained in chapter 1, the surveyed farmers were located in five broadly defined agroecological zones: Northern Highlands, Central highlands, Arussi/Bale region, Hararghe, and Enset. In this empirical specification I included an agroecological zone and

Table 4.3 Definition of variables included in the empirical version of the stochastic production frontier

Variable	Definition
$\ln Y_{ht}$	Logarithm of real value of output
$\ln Area_{ht}$	Logarithm of the hectares of land cultivated
$\ln Over16members_{ht}$	Logarithm of number of household members 16 years and older
$Education_{ht}$	Education level of head of the household
$\ln annualrain_{ht}$	Logarithm of the amount of rainfall received in millimeters in the peasant association
$FertUse_{ht}$	Fertilizer used in kilograms
$Oxen_{ht}$	Number of oxen used for ploughing
$Avlandquality_{ht}$	Average land quality of plots cultivated
hoe_{ht}	Number of hoes used for farming
$Plough_{ht}$	Number of hoes used for farming
$Partnep_{ht}$	Takes a value of 1 if the household participated in an extension program

Note: In each of the notations h and t represent household h and time t, respectively.

a time dummy variable to account for differences in output that could result from variations in weather and overall agro-climatic conditions.

The empirical specification of the inefficiency equation $U_{ht} = Z_{ht}\delta + W_{ht}$ is given by

$$\begin{aligned}
U_{it} &= \delta_0 + \delta_1 Sex_{ht} + \delta_2 Age_{ht} + \delta_3 Education_{ht} + \delta_4 Femaledummy_{ht} + \delta_5 Householdsize_{ht} + \\
&\delta_6 (Noplots * \ln area)_{ht} + \delta_7 (areaha / over16members)_{ht} + \delta_8 Oxendummy_{ht} + \\
&\delta_9 Livestockunits_{ht} + \delta_{10} Noagext_{ht} + \delta_{11} drought_{ht} + \delta_{12} Surveymonth_{ht} + \delta_{13} Elevation_{ht} + \\
&\delta_{14} dst_healthctr_{ht} + \delta_{15} dst_clos_market_{ht} + \delta_{16} dst_PActr_{ht} + \delta_{17} dst_coopoff_{ht} + \\
&\delta_{18} (NorthernHL * 1995)_{ht} + ... + \delta_{21} (NorthernHL * 2004)_{ht} + \delta_{22} (CentralHL * 1994)_{ht} + \\
&... + \delta_{41} (Enset * 2004)_{ht} + W_{ht}
\end{aligned} \tag{4.18}$$

The definition of each of the variables is given in Table 4.4. I included the dummy variable $Femaledummy_{ht}$, which assigns a value of 1 for households that had no male household member age 16 or older to assess the effect of the gender composition of labor force on farming efficiency. $Surveymonth_{ht}$ assigns a value of 1 if household h was surveyed in the months of August through January. Since meher season crops are harvested between August and October, farmers surveyed during or in the months that immediately follow this period can easily answer survey questions as compared to those that are surveyed in the months of February through July. By including this variable I intend to account for measurement error that could be created by inaccurate recalling. The dummy variables associated with parameters δ_{18} through δ_{41} are interactions of the time dummy variables with agroecological zone dummy variables. These dummy variables are meant to capture regional, socio-economic and administrative differences that may affect farming efficiency and parameter estimates of these dummy variables measure efficiency gains within a zone over time. Although these dummy variables are specified in identical ways for the stochastic frontier and inefficiency parts of the model,

Table 4.4 Definition of variables included in the empirical version of the inefficiency equation

Variable	Definition
Sex_{ht}	Takes a value of 1 if household head is male or 0 if female
Age_{ht}	Age in years of head of the household
$Education_{ht}$	Education level of head of household
$Femaledummy_{ht}$	Takes a value of 1 if the household had no male household member that is 16 years of age and older, 0 otherwise
$Oxendummy_{ht}$	Takes a value of 1 if the household owns 2 or more ploughing oxen, 0 otherwise
$Noagext_{ht}$	Number of agricultural extension agents in the peasant association
$drought_{ht}$	Takes a value of 1 if crop suffered from drought, 0 otherwise
$Surveymonth_{ht}$	Takes a value of 1 if household was surveyed in the months of August through January, 0 otherwise
$Noplots_{ht}$	Number of plots tilled by the household
$Householdsize_{ht}$	Number of household members
$Livestockunits_{ht}$	Livestock units owned by the household
$Elevation_{ht}$	Elevation in meters of the peasant association
$dst\_healthctr_{ht}$	Distance in kilometers to the nearest health center
$dst\_clos\_market_{ht}$	Distance in kilometers to the closest market center
dst_PActr_{ht}	Distance in kilometers to the nearest peasant association center
$dst\_coopoff_{ht}$	Distance in kilometers to the closest farmers cooperatives office

Note: In each of the notations h and t represent household h and time t, respectively.

the interpretation of the resulting estimates differs. Battese and Coelli (1992) included time variables in stochastic production frontier and inefficiency equations to "account for both technical change and time varying technical inefficiency effects." They argue that the year variable in equation (4.17) account for Hicksian neutral technological change while the year variable in the inefficiency equation (4.18) takes in to account inefficiency changes that occur during the period considered. The authors conclude that "[t]he distributional assumptions on the inefficiency effects permit the effects of technical change and time varying technical inefficiencies to be identified." [P. 9.] In the following two sections I present and discuss the results from estimating the production frontier and inefficiency equations presented above along with the results from a variant to this specification.

4.4 Results and Discussion

Maximum likelihood estimates of parameters of the two-equation system given by equations (4.17) and (4.18) are reported in Tables 4.5 through 4.7. The software package Frontier 4.1 was used for the analysis. The parameters are estimated in a three-step procedure. First OLS estimates of the frontier are calculated. These estimates are unbiased except for the intercept term. Then a two-phased grid search of γ is conducted with the β parameters set to the OLS estimates obtained in the first step. In addition, the intercept and σ^2 are adjusted using a corrected ordinary least squares method, and δ parameters are set to zero.[42] The third step involves using the values selected from the grid search as starting values in a Davidson-Fletcher-Powell Quasi-Newton iterative procedure to obtain the final maximum likelihood estimates.

To assess the implications of using the SFA method I also estimated the OLS version of the empirical model provided by equation (4.17) above (that is, after dropping the inefficiency equation) and checked for negative skewness. All parameter estimates from

[42] Recall that on page 106 we defined σ^2 as the sum of the variances of the inefficiency and random components of the error term.

the OLS regression, except number of ploughs, have the same sign as those obtained using the SFA model. The OLS parameter estimates of mean annual rainfall and number of ploughs are insignificant, unlike the SFA estimates, as we shall see in section 4.4.1. Moreover, all OLS parameter estimates, except those associated with these two variables, are about twice larger as the SFA estimates, implying that parameter estimates of the OLS model also carry the indirect positive contributions made by variables included in the inefficiency equation. The residuals of the OLS estimate are negatively skewed with a skewness value of –2.5. As a rough guide, a ratio of the skewness value to its standard error that exceeds 2 is taken to indicate a departure from symmetry. In this data set this ratio is about 84, clearly indicating that the error terms are negatively skewed and that, holding other factors constant, OLS is less likely to be the appropriate approach to follow.

Three sets of analyses were conducted to serve different purposes. The first analysis jointly estimates the production frontier and inefficiency given by equations (4.17) and (4.18). The second group estimates these same equations but now averaging among households grouped by agroecological zone, (with modifications for regional dummies made as required). This was done to determine if an aggregate production frontiers exist with zone-specific differences, as a basis for investigating the policy implications of such differences. The equations in the third group redeploy the household level data using various other specifications, such as a log-linear production function, to examine the robustness of the Cobb-Douglas results obtained from the first group of estimators and to examine various other questions. The first two groups will be presented in the following sub-section while results from the third group are presented in sub-section 4.4.2. At the end of section 4.4.2 I briefly discuss some caveats associated with this particular analysis. Moreover, to identify those factors that may account for the generally low levels of modern input application, I estimated three binary logistic regressions. I present the results and discussion of this exercise in section 4.4.3.

4.4.1 Results and Discussion: Cobb-Douglas Specification

Parameter Estimates of the Stochastic Production Frontier

All parameter estimates of the production frontier given by equation (4.17) have the expected sign and most are significantly different from zero at 1 percent. An important implication gleaned from the relative magnitude of the coefficient estimates in Table 4.5, is that most of the measured increase in output was attained by increased use of traditional inputs. According to the results, the value of output is highly elastic for changes in the amount of rainfall received in the region, for changes in the size and quality of cultivated land per household, for changes in the numbers of oxen and ploughs used for cultivation, and for changes in the quality and quantity of labor use (which I experimented using various specifications of labor and/or human capital). While the calculated elasticity of value of output for changes in the rate of fertilizer application is among the lowest, the estimated coefficient as well as the calculated elasticity associated with participation in the extension program is one of the highest.[43] Given the existing low level of fertilizer adoption among Ethiopian farmers, I expected high elasticity of output with respect to both fertilizer application and adoption of the extension package. The fact that modern inputs on average contribute little for increased output shows the extent to which agriculture among the surveyed subsistence farmers, which reasonably represent farmers in Ethiopia, relies on such traditional factors as size of cultivated land, amount of rainfall, and number of oxen, and this explains why crop production in Ethiopia is sensitive to changes in the level of use of these inputs.

The elasticity of value of output for changes in the amount of rainfall received 12 months prior to the survey is the highest; underlining the crucial role that rainfall plays in Ethiopian agriculture. The extent of rainfall's importance is manifested also through frequent famines that occur in the country during years of low rainfall. The policy implication of this result is that concerned agencies, in collaboration with farmers, should

[43] See below for the distinction between the value of the estimated coefficients of some of the variables and the elasticities calculated from these estimated coefficients.

strive to seek ways that reduce shocks faced during periods of rain shortfall. This may include constructing small-scale irrigation schemes and water wells that do not require large investment while working towards building large-scale irrigation schemes that can harness the country's largest rivers that have been so far minimally utilized.

Table 4.5 Maximum likelihood estimates of parameters associated with agricultural inputs included in the stochastic production frontier analysis

Variable	Estimated Coefficient	t-ratio	Calculated elasticity
Constant	3.664*	10.375	
Area of cultivated land	0.162*	10.04	0.162
Household members 16 years and older	0.142*	5.844	0.142
Level of education	0.185*	4.392	0.203
Amount of rainfall 12 months before the survey	0.585*	10.933	0.585
Amount of Fertilizer used	0.002*	11.986	0.097
Number of ploughing oxen	0.111*	5.302	0.148
Average land quality	-0.106*	-8.708	-0.242
Number of hoes used	0.112*	6.11	0.112
Number of ploughs used	0.025	1.323	0.027
Participated in New extension program	0.192*	3.421	0.212

Notes: 1. Parameter estimates with * are significant at 1 percent of level of significance.
2. The analysis uses logarithm values of area of cultivated land, household members 16 years of age and older, and mean annual rainfall.
3. The panel data contained 6,486 cases. The numbers of households used in the analysis are 1,369, 1305, 1,331, 1,224, and 1257 from rounds 1, 3, 4, 5, and 6, respectively.

The second most important input to which the real value of output is highly elastic is the size of cultivated land. While this result emphasizes the importance of conventional inputs in such subsistence agriculture it also indicates that future growth in output from such factors is unsustainable given that the average rate of population growth during the survey period was 2.9 percent (WDI 2008) and that the available land that can be brought under cultivation is limited. The elasticity of value of output with respect to the number of household members 16 years of age and older, which is used as a proxy for labor and which probably is the most abundant resource in rural Ethiopia, is among those traditional inputs that have moderate effect. I included level of education in the production frontier to see the contribution of human capital towards increased productivity. Both the parameter estimate and calculated elasticity of this variable are higher than the one for labor. Such relatively considerable elasticity of value of output with respect to education is encouraging and implies that expanding primary education to rural areas is rewarding, since most of the farmers that were literate had only primary education. Expansion of primary education to rural Ethiopia is one of the areas that the current government is performing well and the only one of the Millennium Development Goals that Ethiopia is expected to fulfill (UNDP 2004).

The estimated production frontier was specified such that the amount of fertilizer used, average land quality, and the numbers of ploughing oxen, hoes, and ploughs used were included in a linear not log-linear fashion. Therefore, the coefficient estimates of these variables do not represent the elasticity of output to the respective inputs. Instead they represent the change in the logarithm of the real value of output for a unit change in the respective inputs. That is, for these variables, $\beta_j = \partial \ln Y_{ht} / \partial X_j$, and the elasticity of value of output with respect to these inputs is calculated as $E_{YX} = (\partial \ln Y_{ht} / \partial X_{ht}) * X_{ht}$, where E_{YX} is the elasticity of value output with respect to changes in input X, Y_{ht} is value of output, and X_{ht} is mean value of input X, where X is either of the inputs listed above. Accordingly, the elasticity of output for increased use of fertilizer is close to 0.1, The respective elasticities of output to changes in numbers of oxen, hoes and ploughs used are 0.15, 0.11, and 0.03, while the elasticity of output for deteriorated land quality is 0.24.[44]

At 0.1, the elasticity of output for increased application of fertilizer is one of the lowest. One can use this low elasticity to justify the current little or no fertilizer application rates

[44] To check for consistency of the calculated elasticities I estimated the production frontier converting all inputs and value of output to logarithms, whereby the estimated coefficients represent the elasticity of output with respect to the inputs. The estimated elasticities on education, fertilizer use, adoption of extension package, average land quality, and number of hoes used are close to the calculated elasticities, while the estimated elasticities on number of oxen and ploughs used are different from the calculated elasticities by a factor of six and seven, respectively. Since many of the variables in this group can be zeros I had to replace them with small positive values, which could have contributed for the difference in the calculated and estimated elasticities.

in Ethiopia. However, fertilizer application rates have to be accompanied with sufficient use of complimentary inputs such as water to achieve the desired results. Nevertheless, the data indicate that the rate of fertilizer application is significantly negatively correlated with average annual rainfall (Appendix 4.B). This justifies the argument that encourages a synchronized and increased application of modern inputs such as fertilizer with other complimentary inputs such as irrigation. In addition, an important point that should be recalled is the fact that the estimated coefficients as well as the computed elasticities consider the mean value of fertilizer application rates of farmers that both do and do not apply fertilizers. In an effort to see the effect of fertilizer application rates only on those that apply fertilizer I estimated the production frontier and inefficiency equations excluding households that do not apply fertilizer. The analysis was conducted on 885 of the farmers that applied fertilizer at one or more of survey rounds; the total number of data points was 2,604, about 40 percent of the aggregate, 6,486. The estimated coefficients are similar to the coefficients in Table 4.5. However, the calculated elasticity of value of output with respect to fertilizer is 0.21, which is the second largest in magnitude next to the elasticity with respect to annual rainfall, indicating that value of output is highly elastic with respect to fertilizer application among those that use it while its effect among an average farmer is small as most farmers do not apply fertilizer. Moreover, the elasticity of value of output with respect to adoption of the New Extension Program is the third largest, indicating that a synchronized use of modern inputs contributes significantly towards increases in output. This is in line with the argument for modernization of traditional agriculture and the result encourages the current government and various agencies that work towards achieving this goal.

Another important aspect of this part of the estimated model is the implications of the parameter estimates associated with the dummy variables on time and agroecological zones. Bear in mind that these dummy variables are specified so as to compare the production frontier of the Northern Highland agroecological zone in 1994 with frontiers of other agroecological zones at different time periods, and with its own frontier in other time periods. For instance, to compare the production frontier of Northern Highlands in

1994 with that of Hararghe in 1999 we need to insert a value of 1 for the 1999 and Hararghe dummies, which takes the intercept of the production frontier down by -012, indicating that the production frontier of the Hararghe agroecological zone in 1999 is relatively inferior to the frontier that Northern Highlands had in 1994. In fact, the production frontiers of the remaining four regions are inferior relative to Northern Highlands. However, all five agroecologic regions improved their performance in terms of achieving higher production frontiers during the survey years of 1994 through 2004.

Calculating elasticities of the real value of output with respect to factors that are represented by dummy variables requires a different method than the one used above because the term $\partial \ln Y_{it} / \partial X_j$ is not defined for a dummy variable as it is discontinuous and takes values of only 0 and 1. Halvorson and Palmquist (1980) argue and show that the elasticity of value of output with respect to a dummy variable is given by $E_{YX_{Dl}} = Exp(\beta_{Dl}) - 1$, where X_{Dl} represents the dummy variable, β_{Dl} is its estimated coefficient and Y is value of output.[45] I used this formula to calculate elasticity of value of output with respect to education, participation in the extension package, and time and agro-ecologic zone dummy variables.

To understand the distinct frontiers faced by different agroecological zones and time periods we need to look into the inherent features of each of the villages relative to the ones in the Northern Highlands agroecological zone and specifically to what the later villages experienced in 1994. Socio-economic studies conducted on the 15 peasant associations included in the surveys describe Geblen, one of the three villages in the Northern Highlands agroecological zone, as a region where rainfall is erratic and

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[45] Let us define Y in equation (4.17) as $Y = Exp[\sum_j \beta_{kj} X_{kj} + \sum_l \beta_{Dl} X_{Dl}]$, where variables X_{Dl} are dummy variables, β_{Dl} are their corresponding estimated coefficients, X_{kl} are the rest of the variables, and β_{kl} are their corresponding estimated coefficients. Then using the basic definition of elasticity of Y with respect to X, holding other variables constant, $E_{YX} = (\frac{Y_1 - Y_0}{Y_0})(\frac{X_0}{X_1 - X_0})$, provides us the result above. Here Y_1 and Y_0 represent value of output when dummy variable X is 1 (X_1) and 0 (X_0), respectively.

Table 4.6 Maximum likelihood estimates of time and agroecologic zone dummy variables included in the stochastic production frontier

Variable	Estimated Coefficient	t-ratio	Calculated elasticity
1995 dummy	0.501*	8.610	0.650
1997dummy	0.110**	1.968	0.116
1999dummy	0.074	1.39	0.077
2004dummy	0.198*	3.817	0.219
Central Highlands	-0.077	-1.449	-0.075
Arussi/Bale	-0.065	-0.958	-0.063
Hararghe	-0.190*	-2.662	-0.173
Enset	-0.144*	-2.651	-0.134

Note: Parameter estimates with * and ** are significant at 1 and 5 percent of levels of significance, respectively.

inadequate, entirely inhabited by poor residents, and a region where the fertile top soil has been washed away leaving rocky fields that are difficult to till (Gebre Egziabher and Tegegne 1996). The other two villages, Harresaw and Shumsheha, face similar climatic conditions and difficulties. Moreover, this agroecological zone represents a region where most of the civil war that lasted from 1973 until 1991 was staged. As a result of this in 1991 the newly established Transitional Government of Ethiopia issued an official decree to reconstruct the war torn and resource poor region, which may have served to partly recover productivity losses suffered during the war as much as it helped achieve higher levels of productivity during later years.[46]

After having accounted for changes in output that could result from price variations using real value of output, the time dummy variables are meant to capture the Hicksian neutral technological change that occurred during the 1994 to 2004 period.[47] Parameter estimates of the coefficients on these dummy variables support the argument that there have been successful technical improvements among Ethiopian farmers, although such

[46] Analysis conducted using nominal value of output place the production frontier of Northern Highlands as the most inferior. Although more data is needed to make the claim, I suspect this region comprises farm households that are least integrated to the market that fetch some of the lowest prices for the output they sell resulting in inferior production frontiers when only nominal values are considered.
[47] The parameter estimates of the time dummy variables in the model that did not account for price changes all overestimate, except the one for 1995, as they include the additional effect of the omitted price effect.

improvements were erratic and seem to stay stable during later years. This could result from government's effort to help farmers intensify their use of modern inputs in what is known as Agriculture-led Industrialization Strategy, and through such efforts as the New Extension Program carried out by Ministry of Agriculture and the extension program undertaken by Sasakawa-Global 2000 (Federal Democratic Republic of Ethiopia 2002).

Improvements from such technical improvements that are not captured by the data require further investigation. This is especially important given that output per hectare has consistently grown (Table 3.17) while the number of farmers applying fertilizer declined during the 11-year period (Table 4.7). Out of those who applied fertilizer only 4 percent applied during all survey periods while 37 percent applied only at one survey period or another. Chapter 3 presented aggregate and household level data that corroborate the claim that fertilizer is the widely used modern input in Ethiopia while it was also shown that fertilizer application rates in Ethiopia were dismal relative to others. While the time dummy variables that are meant to capture Hicksian neutral technical improvements that happened between each survey period I do not claim the sources of such improvements.

Table 4.7 Number of households that applied at least 10 KGs of fertilizer at each round of survey

Number of survey periods fertilizer was applied	Period					Number that applied fertilizer at all	Proportion of those that applied at different survey periods out of those applied at all
	1	2	4	6	11		
1	477	147	140	87	20	871	0.37
2		298	227	102	26	653	0.27
3			268	171	40	479	0.20
4				216	65	281	0.12
5					98	98	0.04
Total	477	445	635	576	249	2382	

Source: Data from survey rounds 1, 3, 4, 5, 6.

To investigate the type of returns to scale that existed among the surveyed farmers I tested the null hypothesis of constant returns to scale against the alternative hypothesis that the production function is not constant returns to scale. That is, the null hypothesis $H_0 : \beta_1 + \beta_2 + ... + \beta_{10} = 1$ was tested. The test concludes that the data do not contradict the hypothesis of constant returns to scale.[48] This result is important to farm households and policy makers alike as it signals the type of return they could expect if they decide to expand production.

In conclusion, there are three important observations that can be deduced from this part of the analysis. First, the majority of output increases among subsistence farmers stem from increased use of conventional inputs because most farmers do not use modern inputs, including 60 percent of the cases where fertilizer was not applied. Second, in the long run, increased output levels can be realized only by increased application of modern inputs, as decreasing marginal returns to conventional inputs will set in given fixed land size; as is already being witnessed for labor. Third, current low levels of contributions of modern inputs towards increased output can be improved by a synchronized application of modern and conventional inputs, as implied by the correlation of such inputs provided in Appendix 4.B, by the higher elasticity for application of the extension package relative to the low elasticity for fertilizer application. Policy makers can use these observations to prioritize the support they provide in a timely manner. In the short run, seeking ways to increase farmers' entitlements of such traditional inputs as land and oxen, and the construction of small-scale irrigation schemes and water wells will help increase farm output. Such efforts should simultaneously be undertaken together with efforts that have longer-term effects. This includes, but is not limited to, improving the availability of expanded extension services, and of such social infrastructure as educational institutions, better roads, health facilities, and more importantly, large-scale irrigation schemes that can reduce the output shocks that risk farmers during seasons of low rainfall.

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[48] I used the test statistic $[R\hat{\beta} - q]' \bullet [R(X'X)R']^{-1} \bullet [R\hat{\beta} - q] / S^2$ where R is given by the vector [0 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0], q is 1, S^2 is sample variance while X is the design matrix. This statistic has an F distribution at (1, n-k) degrees of freedom. The calculated value of the test statistic is essentially zero.

Parameter Estimates of the Inefficiency equation

What is implied by parameter estimates of the inefficiency equation is also an important contribution of this study. Almost all of the parameter estimates are significant and have the expected sign (Tables 4.8 and 4.9). This equation is an empirical version of the equation $U_{ht} = Z_{ht}\delta + W_{ht}$ where U_{ht} represent the technical inefficiency level of farmer h at period t, Z_{ht} are farm household, peasant association and agroecologic zone-specific variables that are assumed to affect efficiency, and δ is a set of parameters to be estimated along with the production frontier parameters. W_{ht} is a random variable that is assumed to be distributed with zero mean and variance σ_w^2. Since the regressand is the index of inefficiency, factors that increase inefficiency have positive parameter estimates.

Age of head of the household is included in the inefficiency equation to examine the effect of experience and physical strength on efficiency. Although not significant the positive sign of the estimated value of this variable supports the argument that farmers become less efficient through age. This could result not only from efficiency loss as farmers get old but also because younger farmers tend to be better educated and open to new methods and techniques. While the direct effect of education on efficiency is captured by the education variable included in the analysis, age, simultaneously with level of education, may be capturing the indirect effect of education such as better administration skills. The data indicate that younger farmers tend to be better educated, since age and level of education have a significant negative correlation. Education plays a role in agriculture by changing farmers' attitudes towards modern technology and enabling them read printed material. However, this is not reflected by the parameter estimate of the education variable included in the inefficiency equation, which essentially shows that education has no effect on farming efficiency.

However, previous analysis that used nominal value of output concluded that education affects efficiency positively. Together with this, the implied positive contribution of education on output growth that I discussed in the previous section warrants expanding education. Thus, one policy parameter to reduce farming inefficiency is to expand education in rural areas and encourage participation by children and rural residents. In particular rearranging the academic year to coincide with periods when less labor is required on farm will likely increase participation rates, given that one of the problems in rural Ethiopia is that children are withdrawn from school during peak agricultural periods of land preparation and harvest.

Sex of the head of the household was included to examine if gender has any bearing on efficiency, the parameter estimate of this variable is negative. However, it is arguable that the negative sign of the estimated coefficient implies that females are less efficient per se than males. Rather it may imply something that is inherent in the family system of rural Ethiopia. Females become head of a household only when males are deceased or not around, therefore when females are head of the household they take on farming in addition to their traditional homemaker role. In male-headed households females participate in agriculture especially in removing weeds, in addition to homemaking. The parameter estimates are, therefore, most probably the implications of scarcity of labor in female-headed households and the reduced attention they could afford to allocate for farming, as they also have to take care of the household. This claim could have been strengthened had the surveys included detailed household level labor use data.

The claim is also supported by the significant negative correlation of the female dummy with both number of household members 16 years and older, and family size of the household.[49] Low levels of farming experience could also have a negative effect on efficiency as females start farming after males are deceased. Associated with this, the estimated coefficient on the female dummy variable is positive, large, and significant. This indicates that, holding other factors constant; households with one or more male members are more efficient than households with all-female working members. The justification given above for the estimated coefficient on sex of head of the household applies here too. I also included family size in the inefficiency equation to determine if it

[49] Recall that the female dummy variable assigns a value of 1 for households that do not have male members 16 years and older.

plays a role in affecting efficiency. Households with fewer members are less efficient compared with larger sized households. In the absence of well-functioning labor markets, larger households face fewer labor bottlenecks at critical points in the farming cycle such as land preparation and harvest.

Table 4.8 Maximum likelihood estimates of the inefficiency function parameters

Variable	Coefficient	t-ratio
Constant	41.019*	20.220
Sex	-2.039*	-3.346
Age	0.003	0.280
Level of education	0.413	0.666
Female dummy	3.440*	3.972
Household size	-0.210*	-3.494
Number of plots* log of cultivated area	-0.223*	-7.157
Cultivated area/ number of members 16 years and older	-0.002*	-2.380
Oxen dummy	-1.747*	-2.629
Livestock units	-0.106**	-2.214
Number of agricultural extension agents in peasant association	-2.629*	-6.508
Crop affected by drought	0.909	1.537
Survey month	6.298*	10.458
Elevation	-0.004*	-22.299
Distance to health center	-0.042*	-4.064
Distance to closest market	-0.251*	-22.069
Distance to nearest PA center	0.175*	22.045
Distance to cooperatives office	-0.288*	-23.32
Sigma-squared	43.994*	31.59
Gamma	0.992*	2274
Log likelihood	-12191	

Note: Parameter estimates with * and ** are significant at 1 and 5 percent of levels of significance.

The interaction variable created by multiplying the number of plots that farmers cultivate with the logarithm of size of cultivated land is included in the analysis to assess the effect on farming efficiency of dissected plots for a given size of cultivated land. The negative coefficient on this parameter implies that for a given number of plots cultivating larger plots reduces inefficiency. The sign on this coefficient may also represent the reduced risk that different plots provide if the plots are located sufficiently disbursed, such that farmers face different degrees of weather-induced variation and mineral content on the different plots.

Another interaction variable that was created by taking the ratio of the size of cultivated land over the number of household members 16 years and older was used in the inefficiency equation to investigate the claim that congested agricultural land holdings adversely affect efficiency and to quantify the magnitude of this effect. The result implies that for a given amount of labor, increase in the size of cultivated land leads to lower inefficiency, which is to say that households that have little land per household member of ages 16 and older are more inefficient, although the magnitude of the adverse effect is small. This estimate supports the result that I present later, which negates the hypothesis that smaller farmers are more efficient.

The estimated coefficient on oxen dummy implies that owning two or more ploughing oxen substantially reduces inefficiency. Oxen are the major source of ploughing power in Ethiopia. Typically, two oxen are needed to pull a plough, which puts households owning one or no ox at a relative disadvantage. Traditionally, farmers with one ox use the arrangement that is known as ‘Mekenago’, where by farmers borrow or exchange oxen in return for ploughing services provided by their own animals. Although I do not have data on oxen rentals, it is common practice for farmers to rent animals for ploughing. Therefore, the estimated coefficient of this dummy variable indicates that farmers that do not have at least two oxen suffer from insufficient ploughing power. Livestock unit is a variable used as a proxy for wealth of farming households. The estimated coefficient of this variable is significant and has the expected sign. Farmers with more animals, which can readily be converted to money, can be able to buy additional modern inputs (such as fertilizer) and other modern inputs that were not included in the list of measured inputs (such as pesticides), than those that do not have animals. Moreover, families with more animals are more likely to have larger protein intake than those with fewer animals, which helps improve their working efficiency.

The analysis indicates that farmers residing in peasant associations with larger numbers of agricultural extension agents are less inefficient. The considerable magnitude of the estimated coefficient indicates the importance of such agricultural infrastructure on farming efficiency. This result encourages those that are working towards modernizing the subsistence agriculture in Ethiopia, and has the policy implication that increasing the number of agricultural extension staff at the existing agricultural extension centers and opening new centers can reduce farming inefficiency among subsistence farmers.

The dummy variable on drought is included to control for one of the factors that affect farming efficiency but are beyond farmers' control. On average, farmers that did not suffer from drought produced 45 percent more output compared with farmers whose crops were adversely affected by drought and yield per hectare among households that went through a dry season was less than one tenth of output per hectare of the remaining households. This result, together with the parameter estimate on mean annual rainfall included in the production frontier, indicates the extent to which agriculture among the surveyed subsistence farmers relies on rainfall and explains why crop production in Ethiopia is sensitive to variation in the amount of rainfall. The implication of this result is that government and concerned agencies should pay significant attention to alleviate problems associated with water scarcity through such measures as construction of small-scale irrigation schemes and water wells.

The estimated coefficient of the dummy variable that takes a value of 1 if a household was surveyed in the months of August through January indicates that farmers surveyed in the months farther away from the harvest period overstate the amount of output they produced or understate the amount of inputs they used. This variable is included in the analysis to control for the recall or measurement error that could arise from delayed interviewing. The magnitude of the estimated coefficient implies that such errors were of considerable magnitude.

Four variables on distances that households had to travel to centers where they access essential services were included in the analysis to investigate the effect of the availability and proximity of social infrastructure on farming efficiency. The estimated coefficient of the distance to the nearest health center had the wrong sign when real value of output is considered as regressand, although it had the right sign when nominal value of output is used. The justification for arguing longer distances to the nearest health centers affect efficiency adversely is that farmers that lived closer to health centers were healthier because they can visit the centers frequently and that they saved travel time to the centers that they used to tend their farms. The coefficient on the distance to markets indicates that farmers living farther away from markets are more efficient compared with those that are closer to markets. Discussions with researchers involved in collecting the data indicate that farmers closer to markets are frequently engage in non-farming production and non-productive activities, such as drinking. Moreover, the researchers indicated that most of the villages that are farther away from markets are high potential areas as compared to those early-settled areas that now are closer to markets.[50] So, this variable may be capturing the effect of other factors on efficiency rather than access to markets.

The analysis indicates that farmers that lived closer to peasant association centers, where support from Ministry of Agriculture is provided, were more efficient than those that were located farther away. Farmers that are located closer to peasant association centers can have easier access to services provided by the centers and extension agents can visit them frequently. By contrast farmers located closer to cooperatives offices are less efficient. Farmers' cooperatives were formed during the Marxist regime that governed the country between 1973 and 1991. Most of the cooperatives were dissolved after 1991 due to strict internal regulations and the inefficiency inherent in the cooperatives. The results imply that in areas where such cooperatives still operate, farmers are less efficient compared with those that operate their individual farms. The estimated coefficient on elevation indicates that highland farmers in are marginally more efficient.

To check for the joint explanatory power of the variables in the inefficiency equation I estimated the model without these variables - that is, the hypothesis $H_0 : \delta_1 = \delta_2 = ... = \delta_{11} = \delta_{41} = 0$ was tested against the alternative hypothesis that these variables jointly explain inefficiency. The test statistic of this claim is calculated using

[50] I thank Drs. Mulat Demeke and John Hoddinott for the insights they provided me on this variable.

the formula –2(log likelihood under H_0 - log likelihood under H_A). This statistic has a χ^2 distribution with degrees of freedom equal to the number of restrictions, in this case 41. The null hypothesis was rejected as the test statistic is 4,363, implying that the data support the claim that the variables jointly explain farming inefficiency.

Recall that the variance of the composed error term ε_{ht} is defined as $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and that I also defined $\gamma = \sigma_u^2 / \sigma^2$ to derive equation (4.16), from which we can calculate $\sigma_u^2 = \sigma^2 - \sigma_v^2$ and $\sigma_v^2 = \sigma^2(1-\gamma)$. The value of γ measures the proportion of variation in the inefficiency component, given by σ_u^2, out of the total variation in ε_{ht}. In the estimated model this variation of the inefficiency component explains more than 99 percent of the total variation in ε_{ht}, and the estimated coefficient of γ is significant. Using the formulas given above, the calculated value of σ_v^2 is 0.35. The corresponding value of σ_u^2 is 43.64. This signifies that the use of stochastic frontier analysis was appropriate, as the total variation of the error term would have been considered idiosyncratic had we used ordinary linear regression.

As discussed above, the estimated coefficients on the time and agroecological zone dummy variables included in the production frontier represented shifts of a given agroecological zone's frontier at a given period relative to the frontier faced by Northern Highlands in 1994. As such, these dummy variables determine the technology faced by farmers in a given zone at a given period because they determine the intercept of the production frontier faced by those farmers. On the other hand, the estimated coefficients of the time-zone interaction dummy variables in the inefficiency equation are interpreted as efficiency gains or losses of farmers in a given agroecological zone at a given period relative to their performance in the previous period, given the different production frontiers faced by the zone at each period.

Table 4.9 summarizes estimates of parameters δ_{18} through δ_{41}. All of the 24 estimates are significant. The estimated coefficients imply that farmers in the Northern Highlands were less efficient in 1995 than in 1994, even if they had a superior production frontier in 1995. This loss in efficiency was regained in 1997 and more so in 1999, which remained stable by 2004. Efficiency level comparisons of farmers in the Central highlands across the 1994 to 2004 period indicates that farmers in this zone experienced efficiency losses between 1994 and 1995 while they had efficiency gains for the rest of the period, and the gains had been stable between 1999 and 2004. Similar comparisons can be made for other agroecological zones and periods, and the comparisons become clearer when reading Table 4.9 together with Table 4.10.

Table 4.10 lists average efficiency levels of farmers living in each agroecological zone and limited to a particular peasant associations with in each of these agroecological zones. Each farmer's degree of farming efficiency can be calculated using the formula $TE_{ht} = \exp(-U_{ht})$, which was given by equation (4.9). The best farmer that lies on the frontier scores a value of 1 while the value gets closer to zero as farm efficiency falls. Since this way of measuring efficiency compares farmers with their own peers, it is

Table 4.9 Maximum likelihood estimates of time and agro-ecology zone dummy variables included in the inefficiency equation

Agroecological Zone	Variable	Year 1994	1995	1997	1999	2004
Northern Highlands	Coefficient	--	14.655	-14.603	-29.025	-28.503
	t-ratio	--	13.023	-10.658	-25.630	-24.086
Central Highlands	Coefficient	-21.160	6.579	-18.109	-28.507	-29.170
	t-ratio	-11.703	5.640	-11.152	-19.533	-22.450
Arussi/Bale	Coefficient	-10.665	3.215 [a]	-24.977	-13.595	-32.082
	t-ratio	-6.341	2.153	-10.138	-7.939	-26.697
Hararghe	Coefficient	-29.535	-8.223	-27.406	-36.503	-45.562
	t-ratio	-13.421	-4.489	-12.592	-16.447	-27.442
Enset	Coefficient	-11.383	-2.688 [b]	-9.526	-20.743	-35.469
	t-ratio	-7.191	-1.772	-6.775	-13.418	-27.654

Source: Calculated from efficiency scores of farm households reported in the SFA analysis.
Note: All parameter estimates are significant at 1 percent except a. which is significant at 5 Percent and b. which is significant at 10 percent.

justifiable to say that farmers can achieve the highest possible efficiency level if what constrains them is solved. Average farming efficiency of the surveyed farmers across the years included in the survey was 0.40, indicating that most farmers were less than one-half efficient relative to those operating at the frontier. Even allowing for data errors and differences in agroecology this constitutes substantial differences in efficiency.

The time-zone dummy coefficient estimates summarized in Table 4.9 can be mapped on to the efficiency estimates given in Table 4.10. In 1995, decline in average efficiency of farmers mainly in Geblen and Shumsheha peasant associations of Northern Highlands contributed to poor efficiency ratings for farmers in this agroecological zone relative to their performance in 1994 (Table 4.10). The average efficiency level of farmers in this zone in 1994 was 0.163, about 8 times the level in 1995, hence the estimated efficiency

Table 4.10 Average efficiency estimates of farmers by agroecological zones and peasant associations

Agroecological zone/ Peasant Association[a]	1994	1995	1997	1999	2004	Average across Years
Northern Highlands	**0.163**	**0.021**	**0.295**	**0.396**	**0.372**	**0.249**
Haresaw	0.002	0.048	0.357	0.416	0.301	0.225
Geblen	0.107	0.001	0.147	0.282	0.364	0.180
Shumsheha	0.197	0.011	0.183	0.368	0.455	0.243
Central Highlands	**0.406**	**0.237**	**0.394**	**0.512**	**0.559**	**0.422**
Dinki	0.481	0.254	0.405	0.580	0.573	0.459
Debre Birhan	0.338	0.259	0.476	0.505	0.574	0.430
Yetemen	0.297	0.014	0.342	0.457	0.426	0.307
Turufe ketchema	0.642	0.472	0.558	0.578	0.501	0.550
Arussi/Bale	**0.401**	**0.289**	**0.531**	**0.456**	**0.538**	**0.443**
Sirbana Godeti	0.214	0.145	0.510	0.356	0.567	0.358
Korodegaga	0.450	0.336	0.481	0.499	0.609	0.475
Hararghe	**0.549**	**0.357**	**0.512**	**0.618**	**0.647**	**0.537**
Adele Keke	0.549	0.357	0.512	0.618	0.647	0.537
Enset	**0.319**	**0.273**	**0.374**	**0.390**	**0.477**	**0.367**
Imdibir	0.329	0.144	0.342	0.206	0.468	0.298
Aze-Deboa	0.375	0.499	0.510	0.527	0.568	0.496
Adado	0.496	0.357	0.522	0.550	0.414	0.468
Gara-Godo	0.105	0.205	0.277	0.329	0.460	0.275
Do'oma	0.212	0.088	0.104	0.167	0.528	0.220
Average across Zones	**0.368**	**0.236**	**0.421**	**0.475**	**0.519**	

Note: Agroecological zones are in bold while Peasant Associations included in each zone are listed under each zone.

loss given by the parameter estimate of δ_{18}, 14.7. Average farming efficiency of the same zone in 1997 was about 80 percent better than the 1994 level, leading to a negative coefficient estimate for δ_{19}. The strong and significant negative correlation, about –0.9, between average efficiency levels and the estimated agroecological zone dummy variables reflects that the inverse relationship between average efficiency levels and the parameter estimates of the time-agroecological zone dummy variables holds for other zones as well.

Two observations can be made about the coefficient estimates of δ_{18} through δ_{41}, in addition to the fact that these estimates generally support the descriptive analysis conducted in section 3.4. First, farmers in each of the agroecological zones experienced a decline in efficiency between 1994 and 1995 (Table 4.11). Second, the decline in efficiency in 1995 was regained in 1997, continued to grow until 1999, this leveled off by 2004.

Regarding the first observation, Hoddinott (2007) points out that 1995 was recorded one of the lowest crop yields in recent history because of exceptionally low rainfall that was received during the meher season, especially in Northern and Central highlands parts of the country. The drought in 1995 was a continuation of the drought in 1994 and had a cumulative effect in leading to low efficiency ranking in these zones. The loss in output is evident from the average real value of output of this agroecologic zone across the years. Specifically, the average real value of output in Northern Highlands was a bare 57 birr in 1995. Compare this with the 1994 average real value of output of 169 birr and with the 1997 average of 518 birr in this region. The proportion of farm households adversely affected by drought corroborates the data on value of output. In 1994 50 percent of the farmers in Northern Highlands suffered from crop damages caused by drought 1994, while in 1995 34 percent suffered from drought, showing the severity of the blow sustained by the region. While Northern Highlands was the hardest hit region, other agroecologic zones suffered from the same countrywide phenomenon, which explains the average decline in efficiency between these two years.

The second observation concerns the improved farming efficiency across the years 1995 through 1999. Efficiency grew by 146 percent across the survey years and agroecologic zones. However, if we were to remove the most outlying growth in efficiency of Northern Highlands agroecologic region between 1995 and 1997, the average growth is about 20 percent. Improved farming efficiency may be the result of multiple factors. In 1995, the Ethiopian government launched what is called the National Extension Intensification Program (NEIP), with the intention of enhancing the availability of inputs and access to credit for over 32,000 half-hectare plots throughout the country, by adopting the methods that were originally introduced by Sasakawa-Global 2000 (SG2000 2007). In 1996 the NEIP expanded to 320,000 plots. During this period of relative peace and stability the government increased the budget share allocated to economic services and focus its attention on strengthening the economy. This increased focus on economic services was downgraded during the Ethiopia-Eritrea war, which became particularly problematic in 2000. On average the military spending to GDP ratio was about 8.5 percent during the 1998 to 2001 period, more than 3 times the average of the previous four-year period, which was 2.7 percent. This resulted in reduced budget for agricultural services, leading

Table 4.11 Average annual rate of change in farming efficiency

Agroecological zone	Average annual rate of change in efficiency				Average annual rate of change across survey years
	1994 - 1995	1994 - 1997	1997 - 1999	1999 -2004	
Northern Highlands	-0.87	26.1	0.17	-0.01	**6.35**
Central Highlands	-0.42	1.32	0.15	0.02	**0.27**
Arussi/Bale	-0.28	1.67	-0.07	0.04	**0.34**
Hararghe	-0.35	0.87	0.1	0.01	**0.16**
Enset	-0.14	0.74	0.02	0.04	**0.17**
Average annual rate of change across agroecological regions	**-0.41**	**6.14**	**0.08**	**0.02**	

Source: Calculated from efficiency scores of farm households reported in the SFA analysis.

to stagnant levels of production efficiency by 2004. Moreover, the NEIP has reduced its program while SG 2000 had altogether abandoned its extension program in 2000. In addition to these, proportionately more effort and resources are needed to improve upon the higher efficiency level achieved in 1999, resulting in relatively stagnant levels of efficiency between 1999 and 2004.

One more observation in relation to the general patters of efficiency, especially the improvements realized between 1995 and 2004 is that regions that performed poorly during earlier years have attained improved efficiency and were able to narrow the divergence in average efficiency among zones (Table 4.10). The range of average efficiency between the most and least efficient agroecological zones was 0.39 in 1994, 0.34 in 1995, and 0.27 in 2004. One of the reasons for narrowed efficiency gap could be the special attention that was given for regions that were affected by the civil war that ended in 1991; these regions are located mainly in the northern parts of the country.

Shortcomings of Variables Used and the Application of SFA on ERHS data.

In addition to the usual problems associated with measurement error and omitted variable bias that other methods suffer from, the SFA approach may have other shortcomings. These shortcomings warrant the results and implications of the stochastic frontier analysis be interpreted with some qualifications. For instance, the large divergence in efficiency between those operating on and under the estimated production frontiers may actually be the result of other factors than real differences in efficiency.

Although plot level data on measured output was collected in all rounds of ERHS and was more preferred as a regressand, the analysis used household level aggregations of plot level real value of output because data on most factors put into production were collected at a household level. In addition to the detailed information that was lost because of the aggregation, this variable may carry imperfections associated with the price data collected separately from the surveys. Moreover, the average quality of land that is included in the analysis was calculated for each household from plot level quality of land, a household that performed well may be considered inefficient if it owns disproportionately large poor-quality land.

Due to differences in the details of survey instruments implemented to collect data on labor use in different rounds I decided to substitute this variable with the number of household members of 16 years and older. Although the number of household members of 16 years and older better approximate labor use than any other variable in the data set, which constitutes subsistence farmers that largely depend on family labor, it may also lead to wrong estimates and implications. Specifically, a household with few working members that hired laborers to work on the household farm may appear to have superior efficiency than a household that was unable to hire extra labor. A similar problem may arise if a household used some inputs that were not included in the data, such as pesticides.

The problems just discussed may have led to imperfect parameter estimates of the variables in all approaches that estimate production functions. However, the problem is compounded by using the stochastic production frontier approach because the imperfections will pass on to the inefficiency equation that is estimated simultaneously with the production frontier, and the efficiency score of a household, which is derived from the relative position of its real value of output from those that are deemed efficient and operate at the frontier. Notwithstanding these shortcomings, I used the SFA approach because its advantages outweigh these disadvantages.

Zone Level Production Frontier and Inefficiency Equation Estimates

The results above using farm households as the unit of analysis reveals substantial variation among agro-ecologies in the estimated production frontiers and the implied production efficiencies. This suggests there is added value in estimating separate production frontiers and the associated inefficiency equations for each agroecology. The results of such an exercise are provided in Appendices 4.C through 4.F (pages 171 through 174). Appendix 4.F provides the mean values for some of the variables used in the analysis. Real value of output corresponding to each agroecologic zone is used as a regressand while inputs specified in the production frontier given at equation (4.17) associated with parameters β_1 through β_{10} are used as explanatory variables. The inefficiency equation uses the list of household and agroecologic zone specific variables associated with parameters δ_1 through δ_{17} of equation (4.18). Time and peasant association dummy variables were created depending on the number of peasant associations included in each of the zones.

Most of the estimates are significant, and all of them have the expected sign except average land quality in Arussi/Bale agroecologic zone and participation in the extension package, which is not significant in four agroecologic zones. Parameter estimates of zone level production frontiers confirm some of the findings discussed above, in addition to providing some new insights. In all of the agroecologic zones the elasticity of the real value of output was the highest with respect to annual rainfall, while the elasticity with respect to cultivated area was the second highest. The conclusion made in the previous section is reinforced by the separate production frontiers because the elasticity of real value of output with respect to annual rainfall is greater than 100 percent in all but Central Highlands agroecological zone. The largest elasticity with respect to annual rainfall of 3.6 was registered in Hararghe while the smallest, 0.42, was in Central highlands. Similarly, the elasticity of value of output for changes in area of cultivated land ranged between 0.20 in Enset growing region to 0.44 in Northern highlands.

The estimated parameters of the proxy for labor, number of household members 16 years and older, was on average the third important factor of production. Labor is particularly important in the relatively resource rich agroecologic zones located in the south, south eastern, and south western parts of Ethiopia, while it is relatively less important in the Northern and Central highlands. These later agroecologic zones associate relatively higher importance to farming equipment and ploughing oxen. As in the case of the pooled production frontier, the output responsiveness to the amount of fertilizer applied was one of the smallest ranging between 0.002 and 0.004. Moreover, the parameter estimate associated with participation in the extension package is significant only for Central highlands. By contrast, real vale of output almost always increased with increased average land quality. Numbers of hoes and ploughs used had the anticipated positive sign for all zones and were frequently significant, on average the number of ploughs used by the household had marginally larger effect on output than the number of hoes.

Time and peasant association dummy variables were included to investigate if the peasant associations in each zone have realized Hicksian neutral technical change during the 1994 to 2004 period relative to a reference peasant association in 1994.[51] The results indicate that some peasant associations had relatively higher production frontiers where as others had inferior frontiers relative to the reference peasant association. In general, the parameter estimates of the separate production frontiers imply that traditional inputs as a group contributed for much of the output increase in each agroecologic zone. Moreover, the results indicate that with in the category of traditional inputs different inputs are relatively more important in different agroecologic zone. The policy implication of this result is that within the framework of increasing traditional input entitlements of farmers and increasing the availability and use of modern inputs, agricultural policies should ideally be tailored to suit each agroecological zone.

Most of the results in the separate inefficiency equations, given in Appendix 4.D, conform to what was obtained from the pooled equation. Male-headed households are found to be more efficient in all zones. Age has mixed effect; the largest effect of young age for increased efficiency was witnessed in Arussi/Bale agroecologic zone. Where it is significant education affects efficiency positively. Households with at least one male-working member were more efficient. Larger households were more efficient in all zones except the Enset growing zone. Tilling fewer plots for a given area of cultivated land reduces inefficiency in Central Highlands, Hararghe, and Enset zones, while the risk diversifying effect of tilling numerous plots per given cultivated land outweighs the time lost to travel between plots in Northern Highlands and Arussi/Bale agroecologic zones. The estimates imply households with smaller cultivated area per working member are less efficient. Coefficient estimates of other variables, including time and peasant

[51] While four of the agroecologic zones comprised two to five peasant associations, the Hararghe agroecological zone included only Adele Keke peasant association.

association dummy variables, provided in Appendix 4.E, were similar to the estimates in the equation that pooled all agroecological zones together.

Among other things the Northern Highlands is the driest region with the highest return for increased availability of rainfall; therefore, this zone could benefit from irrigation and well-water development projects, the same goes for Hararghe zone which has the second lowest average annual rainfall and the highest elasticity with respect to annual rainfall. In addition to this, almost no farmer in Northern Highlands participated in the extension program and their average fertilizer application rates were next to none during the period covered by the survey. Although fertilizer application rates and participation in extension are low in other regions as well, it is severe in Northern Highlands. Fertilizer application rates in the Enset zone, which was fourth among the five agroecologic zones in average fertilizer application rates, was about 4 times higher than the one in Northern Highlands, while the one in Arussi/Bale, the zone with the highest application rates, is about 40 times higher than application rates in Northern Highlands (Appendix 4.G). Moreover, average land quality in Northern Highlands is the worst while average real value of output in Northern Highlands is 81 percent of the fourth average real value of output attained in Arussi/Bale agroecologic zone. Therefore, this zone is the worst in terms agroclimatic factors, including rainfall and land quality, uses little modern inputs, such as fertilizer and the extension package, and average size of cultivated land in the region was one of the smallest. Policy makers that strive to improve farmers' performance in the region need to work in the fronts that can increase the availability of water and other traditional inputs, increase farmers' awareness about soil conservation, fertilizer application, the extension package, and other modern inputs. Since this zone is one of the early settled areas with high population density, future generations will be forced to reckon with shrinking farm sizes if they choose to stay in agriculture. One way to alleviate this land-holding problem could be to introduce diversified small-scale processing plants to rural areas and encourage farmers' participation through such means as extending credits. To conclude this section, the set of production frontiers estimated for the five agroecologic zones included in the ERHS provide an important insight into the opportunities and problems associated with each agroecologic zone and imply that policy makers should come up with specific policies that suite each agroecologic zone to take advantage of the opportunities and mitigate the problems.

4.4.2 Results and Discussion: Alternative Specifications

To examine the robustness of the results discussed in section 4.4.1 I estimated a number of alternative specifications. Among these the four presented in this thesis are the per-hectare version of the Cobb-Douglas production frontier, a log-linear specification, a Cobb-Douglas version with squared term for area of cultivated land, and OLS estimate of the Cobb-Douglas production function whose residuals are regressed against the variables included in the inefficiency equation. While estimating all the four specifications are useful for assessing the robustness of the results reported above, the third version was intended also to help investigate the hypothesis that smaller farmers are more efficient.[52]

In the production frontier component of the per-hectare specification I divided the values of the regressand, real value of output, and 6 of the explanatory variables given in equation (4.17) by the size of cultivated land, converted those ratios into logarithms and used the resulting data to estimate the frontier. The results are provided in Appendices 4.H through 4.K.[53] Consequently there is one less variable in this equation than in equation (4.17). The inefficiency component of the system uses the same list of variables as in (4.18).

To examine the farm size-efficiency argument I used the logarithm of area squared in the production frontier, in addition to those listed in equation (4.17). I used the logarithm of area of cultivated land in the inefficiency component of the equation, in addition to those listed in equation (4.18). Therefore, each parts of this specification contain one more

[52] I thank Dr. Daniel Gilligan at IFPRI for suggesting testing this claim in the Ethiopian context.
[53] The variables that are converted to per hectare ratios are the number of household members 16 years and older, the amount of rainfall, the amount of fertilizer applied, number of ploughing oxen, and numbers of hoes and ploughs used for cultivation.

variable than the system given by equations (4.17) and (4.18). The results of this specification are provided in Appendices 4.L through 4.O.

The OLS regression that estimates the Cobb-Douglas specification uses the same number of variables as in the stochastic production frontier while the inefficiency-equation like OLS regression that uses the OLS residuals as left dependent variable uses the same variables as in the inefficiency equation.

A straight forward implication of the log linear specification would include the original 10 explanatory variables in equation (4.17) associated with parameters β_1 through β_{10}, the squared terms of 8 of these 10 variables, excluding the dummy variables on education and participation in extension, and a combination of 2 of each of these 10 variables ($_{10}C_2$), which adds 45 variables to the preceding list-a total of 71 variables (including the 8 time-zone dummy variables). However, a descriptive analysis of the 63 variables other than the time-zone dummies revealed that some of the variables were perfectly correlated. Thus I opted to remove interaction variables that had a correlation coefficient exceeding 0.99; 9 variables were removed in this process. So in the final version a total of 62 variables were included in the log-linear specification. The inefficiency component of this specification uses the same list of variables as in (4.18). The estimated results from this last specification are provided Appendices 4.P through 4.X.

Most of the results, especially those that are not converted to per-hectare values were similar, while some of the estimates are exactly the same. Since the interpretation of the variables in the per-hectare specification is different from other cases the difference in the estimates was expected. The estimates of the variables in the inefficiency components of all the three specifications are either the same with the original estimates discussed in the previous section or are very close, so I will discuss them only when necessary.

Estimates of the specification that uses the per-hectare values of measurable inputs show the same pattern in terms of contribution of inputs towards increased output as in the original specification. The amount of rainfall received per hectare of cultivated land had the highest contribution towards increased value of output per hectare of cultivated land, although the elasticity had fallen by 0.129 from the original specification. Labor had the second highest elasticity. The elasticity of value of output per hectare with respect to the amount of fertilizer per hectare used was essentially zero and significant, showing that on average fertilizer is playing an insignificant role in subsistence agriculture. Moreover, the calculated elasticity associated with participation in the extension program was one of the smallest and insignificant.

The number of oxen, hoes, and ploughs used for cultivation had insignificant contribution when considered in per hectare terms. Recall, that these inputs had some of the highest contributions when considered per household. To test for robustness I estimated the equation without converting the number of oxen, hoes, and ploughs used into per hectare values. The coefficient estimate of these variables in this last specification is essentially the same with the baseline result given in Table 4.5, while estimated values of those variables that are converted to per hectare units are similar to the one given in Appendix 4.H.

Excepting the difference in signs of two parameter estimates, coefficients of the inefficiency equation that uses per hectare values are similar to the ones in the original specification albeit insignificant and mixed differences in magnitudes. The two estimates that took a different sign are associated with education, which had the wrong sign in the original specification, and distance to health center, which has the wrong sign in the per hectare specification. In general, the results obtained from estimating the per-hectare production frontier confirm the conclusions that were made in section 4.4.1.

Deolalikar (1981) and Bardhan (1973) investigated the relationship of farm size and farming efficiency using Indian data. The specification they used is a variation of the equation $Y_{ht} = a + b X_{ht} + e_{ht}$, where Y_{ht} is output or output per hectare of household h at time t, and X_{ht} is the size of cultivated land by household h at time t. a and b are parameters to be estimated using the data. Under this specification the error terms e_{ht} are assumed to be mean zero, constant variance, normally distributed, and uncorrelated with X_{ht}. Assuming that this holds for the data used in this study I estimated two equations that use real value of output and real value of output per hectare as regressands. The inverse efficiency-farm size relationship is confirmed if the estimate of b is less than unity if real value of output is used as a regressand, while the estimate is expected to be negative if real value of output per hectare is used. For both of these cases the estimated results obtained using the Ethiopian Rural Household Survey data indicate that the argument of the inverse efficiency-farm size relationship does not hold among Ethiopian subsistence farmers. Moreover, I regressed the estimated efficiency levels of each of the farmers at each period from the baseline regression against the logarithms of cultivated farm size and average land quality following Gilligan (2001). Average land quality is used to control for the inherent mineral quality of the cultivated land. The estimated coefficient on logarithm of cultivated area is 0.021, confirming that farmers' efficiency improves with increase in farm size.

A system of production frontier and inefficiency equation was also estimated to test this claim. In addition to the variables listed in equations (4.17) and (4.18) I used the logarithm of area squared in the frontier and the logarithm of area in the inefficiency equation. The results are provided in Appendices 4.L through 4.O. Most of the results in these tables are either similar or the same as those in Tables 4.5 through 4.8. This indicates that the results are stable and their implication is robust. The estimated coefficient associated with the logarithm of area squared is positive, while the one associated with logarithm of area is negative. Both of the estimates are significant. The results imply that increased farm size contributes for increased output, with the quadratic coefficient dominating for increased values of cultivated area. Moreover, the estimated coefficient associated with area of cultivated land in the inefficiency equation is negative and significant. This implies that increase in farm size contributes to reduced inefficiency. As we recall, 25 percent of the surveyed farmers cultivated 0.38 hectares or less, 50 percent of them cultivated 0.88 hectares or less, while 58 percent of them cultivated a hectare or less. Thus the proposition that small farmers are more efficient may fail to hold among farm sizes that are too small or the inverse relationship may effectively hold among farmers that till a certain range of farm sizes. For instance, this argument may fail to hold among mechanized farms in the United States, which benefit from economies of scale. Further investigation and theoretical work is needed to argue whether the inverse relationship between farm size and productivity holds among farmers in Ethiopia where average farm size is less than a hectare. This also implies that average land holdings in Ethiopia are small and farms are so congested that alternative ways of increasing efficiency are sought.

The last specification estimated to test the robustness of the original analysis was the log-linear specification. There are some stark differences between the estimated coefficients of the baseline Cobb-Douglas specification provided in Tables 4.5 and the parallel estimates of the log-linear specification provided in Appendix 3.P.[54] First, the elasticity of value of output with respect to area of cultivated land in the log-linear specification is larger than 3 times the magnitude in the Cobb-Douglas specification, while the elasticity with respect to annual rainfall is about half of the magnitude in the Cobb-Douglas specification. Second, although not significant, the elasticity of real value of output with respect to number of household members of 16 and older and level of education are negative. Given these observations and given the fact that the marginal effect of these inputs might have been distributed among squared and interaction terms, I calculated the total marginal effect of all of the inputs using the formula:

$$\frac{\partial \ln Y_{ht}}{\partial X_{jt}} = \beta_j + \beta_{jj} \times X_{jt} + \sum_{j \neq k} \beta_{jK} \times X_{kt} \tag{4.19}$$

where Y_{ht} is value of output of household h at time t, X_{jt} is input j at time t, which could also be in logarithm, and β_j, β_{jj}, and β_{jK} are the parameter estimates associated with input j, its squared term, and its interaction terms, respectively. I used the mean

[54] This involves comparing estimated coefficients of the original 10 variables associated with factors of production used in production.

values of the inputs to calculate the total marginal effects. The calculated total marginal effects are provided in Table 4.11, together with estimated coefficients of the Cobb-Douglas specification. The total marginal effects of the coefficients of the log-linear specification are close in magnitude to the estimated coefficients of the Cobb-Douglas specification. Moreover, they have the same implication provided by the Cobb-Douglas specification. That is, most of the increase in the real value of output was attained through increased use of traditional inputs. An important difference between the two specifications is that the elasticity of real value of output with respect to annual rainfall falls second in importance next to the total marginal effect of area of cultivated land. However, this could be the result of the absence of the interaction terms of annual rainfall with other variables (Appendix 4.R). All the 9 variables removed due to high correlation with the remaining variables involved annual rainfall, so its effect may have been captured by increased contribution of the remaining variable, including area of cultivated land.

This specification conforms to other specifications by the fact that the calculated total marginal effect of fertilizer is one of the lowest. Even if the total marginal effect of

Table 4.12 Calculated total marginal effects of estimated coefficients using the log linear specification relative to Cobb-Douglas specification

Variable	Total marginal effects (Log-linear)[a]	Estimated coefficients (Cobb-Douglas)[b]
Constant	5.010	3.664
Area of cultivated land	0.334	0.162
Household members 16 years of age and above	0.198	0.142
Level of education	0.115	0.185
Amount of rain 12 months before the survey	0.258	0.585
Amount of Fertilizer used	0.003	0.002
Number of ploughing oxen	0.109	0.111
Average land quality	-0.041	-0.106
Number of hoes used	0.132	0.112
Number of ploughs used	0.117	0.025
Participated in New extension program	0.170	0.192

Sources: a. Calculated using equation 4.19, estimates of the log linear stochastic production function (Appendices 4.P, 4.Q, and 4.R), and the panel data formed from ERHS rounds 1, 3, 4, 5, and 6.
b. Table 4.5.

participation in new extension program is relatively large the calculated elasticity associated with this input is even lower than the elasticity associated with fertilizer application. As in other specifications the numbers of ploughing oxen, hoes, and ploughs contributed reasonably well, next to rainfall and area of cultivated land. Estimates of the inefficiency equation are the same in sign and mostly close in magnitude to the parameter estimates of the inefficiency equation in the Cobb-Douglas specification.

The purpose of estimating the OLS production function, and regressing the OLS residuals on the inefficiency equation parameters was to examine if the results obtained by making distributional assumptions on the composed error term are robust while using methods that do not make restrictive assumptions such as OLS. The results obtained are presented in Appendices 4.V through 4.X.

The general observations that can be gleaned from the results mostly conform to what were indicated by the stochastic frontier analysis. Traditional input play the most important role, even if the order of importance is altered. When significant all of the variables have the same sign as the SPF estimates. Moreover, estimates of the inefficiency-equation like OLS regression conforms to what was obtained from the simultaneous estimation of the SPF and inefficiency equations whenever they are significant.

This section is intended to investigate the robustness of the Cobb-Douglas specification and assess how they compare with claims made elsewhere in the literature. The general conclusion made earlier hold, and the inverse farm-size efficiency relationship is not witnessed among Ethiopian farmers.

4.4.3 Factors Affecting Extension Package Adoption and Fertilizer Application

The conclusions derived thus far and the policy implications that followed require addressing the problems constraining farmers from adopting and intensifying the application of modern inputs. A full-fledged research on this issue requires a separate thesis and perhaps a data set that is collected to specifically address this issue. I make use of the data set at hand to a previously conducted similar study on Ethiopia to elicit some information as to what household and region specific characteristics affect farmers' adoption of the extension package and fertilizer application, the two inputs that are categorized as modern inputs. This analysis, together with previously conducted analyses, helps to justify some of the policy implications, and in indicating the factors that slow modernizing subsistence agriculture. I estimated three binary logistic regressions (Table 4.12).[55] The first regression estimates the effect of household and region specific characteristics on adoption of the extension package, which takes a value of 1 if the household used the package. The other two regressions are estimated using dummy variables constructed from the criterion: whether or not the farm household applied fertilizer (1 if it did), and whether the household applied 20 kilograms or more per hectare. Some interesting results are obtained.

While sex of head of the household has no effect on whether or not the farmer adopts the extension package or applies fertilizer the gender composition of household labor plays a role in adoption and level of application. In particular, those households with no male member of 16 years and older are as half times likely to apply fertilizer (given by Exp(B) in columns 7 and 10 of Table 4.11). Both illiterate and older farmers are less likely to adopt modern inputs, however, the magnitude of these effects are little. Larger households are more likely to adopt modern inputs as they are less constrained by labor and have more members to feed. Households that own larger farms are less likely to adopt and use little fertilizer. However, for a given size of cultivated land increased

[55] I follow the basic theory of limited dependent variable regression model that assumes a logistic disturbance term (logistic regression) outlined in such common econometrics textbooks as Greene (2002), Maddala (1983) or other standard text books.

availability of labor leads households to adopt and intensify their fertilizer application, as labor becomes less of a bottleneck. For a given number of plots, households that own larger sized plots apply modern inputs than those that own smaller plots. Farmers' level of fertilizer application declines with improved average land quality. Farmers residing in regions adversely affected by draught are at least 27 percent more likely to apply fertilizer while the amount of rainfall received has mixed effects on adoption and application, and farmers' likelihood of adoption and application does not change with amount of rainfall received. Ownership of more animals both in terms of ploughing oxen and tropical livestock units contribute positively for increased application of fertilizer. While the time dummies do not have a clear pattern, we see clear regional distinction. Farmers in Northern Highlands are more likely to adopt the extension package than any other region while the same region lags behind in terms of fertilizer application.

The unexpected result of this exercise is the negative and significant coefficient estimates associated with number of agricultural extension agents in two of the three regressions. Increased support from agricultural extension agents should lead to increased adoption of the extension package and intensification of fertilizer application and not to decline in adoption and application. Further investigation of the data revealed that there is systematic relationship between peasant associations and adoption and fertilizer application. That is, there are peasant associations where there were few or no farmers adopting the package or where little or no fertilizer applied, indicating the fact that in such places there could be other systematic and structural problems that is beyond what the extension agents could solve. I decided to estimate the logistic model for two sets of farmers. The first constituted farmers residing in peasant associations where there is least 6 percent adoption of the package, this resulted in 2445 cases or 37 percent of the total number of cases. The second constituted farmers residing in peasant associations that apply an average of at least 15 kilograms of fertilizer per hectare, which resulted in 4312 cases or 66 percent of the aggregate data set containing 6486 farmers. The first data set was used to investigate factors affecting participation in the extension package while the second was used to investigate factors affecting use and intensity of fertilizer application.

Table 4.13 Logistic regressions of household specific factors affecting Extension package adoption and fertilizer application.

Variable	Participation in the Extension Package			Applied Fertilizer			Applied at least 20 KGs Per Hectare		
	Coefficient	P - Value	Exp(B)	Coefficient	P - Value	Exp(B)	Coefficient	P - Value	Exp(B)
Constant	-2.553*	0.00	0.08	-0.203	0.59	0.82	-0.104	0.79	0.90
Sex	0.174	0.30	1.19	-0.060	0.56	0.94	0.066	0.51	1.07
Age	-0.001	0.87	1.00	-0.006*	0.00	0.99	-0.006*	0.00	0.99
Level of education	0.225***	0.10	1.25	0.172**	0.05	1.19	0.120	0.18	1.13
Female dummy	-0.003	0.99	1.00	-0.674*	0.00	0.51	-0.766*	0.00	0.46
Household size	0.012	0.57	1.01	0.119*	0.00	1.13	0.100*	0.00	1.10
Number of plots* log of cultivated area	-0.017	0.33	0.98	0.120*	0.00	1.13	0.135*	0.00	1.14
Cultivated area/ number of members 16 years and above	-0.007	0.79	0.99	-0.224***	0.10	0.80	-0.273**	0.05	0.76
Livestock units	-0.036	0.23	0.96	0.110*	0.00	1.12	0.104*	0.00	1.11
Number of ploughing oxen	0.069	0.38	1.07	0.016	0.75	1.02	0.092**	0.05	1.10
Average land quality	0.029	0.47	1.03	-0.107*	0.00	0.90	-0.083*	0.00	0.92
Area of cultivated land	-0.029	0.71	0.97	-0.238*	0.00	0.79	-0.747*	0.00	0.47
Crop affected by drought	0.500*	0.01	1.65	0.337*	0.00	1.40	0.241**	0.05	1.27

Note: Parameter estimates with *, **, and *** are significant at 1, 5, and 10 percent of levels of significance, respectively.

Table 4.14 Logistic regressions of village specific factors affecting Extension package adoption and fertilizer application.

Variable	Participation in the Extension Package			Applied Fertilizer			Applied at least 20 KGs Per Hectare		
	Coefficient	P - Value	Exp(B)	Coefficient	P - Value	Exp(B)	Coefficient	P - Value	Exp(B)
Number of agricultural extension offices in peasant association	-0.2758	0.00	0.76	0.016	0.78	1.02	-0.098**	0.09	0.91
Distance to health center	0.008*	0.01	1.01	-0.015*	0.00	0.98	-0.016*	0.00	0.98
Distance to closest market	0.000	0.97	1.00	0.013*	0.00	1.01	0.007*	0.00	1.01
Distance to nearest PA center	-0.017*	0.00	0.98	-0.015*	0.00	0.99	-0.010*	0.00	0.99
Distance to cooperatives office	-0.002	0.67	1.00	-0.004	0.40	1.00	-0.008	0.12	0.99
Amount of rainfall 12 months before the survey	0.001*	0.00	1.00	-0.002*	0.00	1.00	-0.002*	0.00	1.00
1995dummy	-0.834*	0.00	0.43	0.004	0.97	1.00	0.046	0.65	1.05
1997dummy	-0.182	0.37	0.83	0.884*	0.00	2.42	0.750*	0.00	2.12
1999dummy	0.887*	0.00	2.43	0.975*	0.00	2.65	0.926*	0.00	2.52
2004dummy	0.489*	0.01	1.63	-0.710*	0.00	0.49	-0.728*	0.00	0.48
Central Highlands	-2.138*	0.00	0.12	2.667*	0.00	14.40	3.040*	0.00	20.91
Arussi/Bale	-1.077*	0.00	0.34	2.928*	0.00	18.69	3.484*	0.00	32.57
Hararghe	-1.035*	0.01	0.36	1.319*	0.00	3.74	2.337*	0.00	10.36
Enset	-1.601*	0.00	0.20	1.722*	0.00	5.59	2.041*	0.00	7.70
-2 Loglikelihood		2973.8			5934.1			5932.5	

Note: Parameter estimates with * and **are significant at 1 and 5 percent of levels of significance, respectively.

In both instances the number of agricultural extension agricultural agents contributes positively to the adoption and intensified use of modern inputs.

Moreover, the estimated coefficient of distance to peasant association center indicates that farmers residing in close proximity to peasant associations are more likely to adopt the extension package, and apply fertilizer in larger amounts, as they are more likely to benefit from the services of the agricultural extension agents in the peasant association centers. Since agricultural extension agents and peasant associations are intended to introduce better farming mechanisms to farmers it encourages that they are achieving this goal. Moreover, the results imply that the Ministry of Agriculture and concerned agencies need to expand to areas that do not have access to such services and intensify their services in areas that already have the infrastructure.

4.5 Summary and Key Findings

A number of stochastic production frontiers with time-varying inefficiency effects were estimated for 1,480 subsistence farm households residing in five agroecological regions in Ethiopia. The number of households surveyed in each round and included in the analysis varied across rounds. The data included in the analysis was collected at five points during an eleven-year period spanning 1994 to 2004. The stochastic production frontier analysis was selected over other options such as the ordinary least squares (OLS) or the data envelopment analysis (DEA) as it enables one to disentangle the idiosyncratic effects that farmers face from household-specific inefficiency effects. DEA methods attribute any shortfalls from the observed maximum production levels entirely to inefficiency effects, while OLS methods attribute such shortfalls from the observed maximum production levels entirely to idiosyncratic effects.

The results indicate that among the Ethiopian farmers in this panel, most of the increase in output was attributable to increased use of traditional inputs. The value of output was highly elastic with respect to the amount of rainfall received in each region. Increases in the size and quality of cultivated land, changes in labor use and/or human capital, and changes in the numbers of oxen and hoes used for cultivation also significantly contributed to increased output. By contrast, the calculated elasticities with respect to the rate of fertilizer application and participation in the official extension program were among the lowest, implying that, on average, these factors contributed little to agricultural output. This indicates that Ethiopian agriculture relies heavily on traditional factors of production, and that crop production in Ethiopia is especially sensitive to changes in the amount of these traditional inputs. The magnitude of the effect of rainfall on output suggests that the government and concerned agencies, in collaboration with farmers, should put a premium on finding ways to reduce the shocks faced during periods of low rainfall. The fact that area of cultivated land plays such a significant role for increased output is a warning that such increased output cannot be attained in the future given the constrained land size and the high rate of population growth that mostly relies on agriculture. In Ethiopia most farmers use either a pair of oxen or simple hand tools to till their land. Due to a shortage of capital and the prospects that the extensive use of (heavy) machinery can exacerbate wind and water erosion it is hard to argue in support of the use of heavy machinery. However, small and medium scale machinery such as those used in similarly dry agricultural areas such as parts of India could be productively deployed in Ethiopia.[56]

Despite the finding that the elasticity of such modern inputs as fertilizer is insignificant on average, the fact that the elasticity is one of the highest among those farmers that use fertilizer calls for increased application of fertilizer among those that already use fertilizer and for its introduction to areas that currently do not use fertilizer.

The results indicate that each of the agroecological zones had gained from Hicksian-neutral technological improvements during the entire period. This has the policy implication that such efforts as Ethiopian government's Agriculture-Led Industrialization Strategy and the extension program be intensified in areas that are already covered, and

[56] This effect of heavy machinery and the type of machinery used in India were indicated to me by Prof. Jonathan Chaplin, Department of Biosystems and Agricultural Engineering, University of Minnesota.

expanded to areas that are not covered by the programs. One can draw from the results that attaining increased output from increased application of only traditional inputs is unsustainable, and plans should be in place for increased application of modern inputs. Descriptive analyses discussed in chapter 3 show some of the fixed inputs, such as land, are already fragmented and decreasing in quality and hence increased application of other traditional inputs, such as labor, will eventually have decreasing marginal returns. In this respect policy makers need to pay attention to factors that facilitate extension package adoption and increased fertilizer application. This requires rethinking the services that agricultural agents and peasant association provide, introduce simple agricultural machinery that help alleviate labor bottlenecks and facilitate the availability of credits that will help farmers acquire ploughing oxen and other inputs.

Education contributes positively to increases in output and reduced inefficiency. Female headed households or households that had labor bottlenecks suffer from increased inefficiency due to the multiple roles played by women. Households that are faced with diversified risk from plots that are located sufficiently apart appear more efficient while households that had less land per working member are more inefficient. Households that own more animals either in terms of two or more ploughing oxen, or total livestock units are less inefficient. Households residing in peasant associations with expanded agricultural extension services are considerably less inefficient. Drought affects efficiency adversely whenever it strikes. Farmers that live in close proximity to markets and cooperatives offices are more inefficient. On average farming inefficiency has consistently declined in the period considered. The results suggest that each agroecological zone faces with different opportunities and obstacles, and as such policy makers need to take a close look at each of the zones before implementing uniform changes that concern all of the zones.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

Ethiopia, the twelfth poorest country in the world in 2005, has an agricultural sector that contributes about 50 percent towards its GDP and about 85 percent of its population resides in rural areas. However, the sector has always performed poorly. Agricultural value added per agricultural worker remains among the lowest in the world. About 45 percent of the residents in rural Ethiopia live below the national poverty line, and the rural population is endowed with few and poorly provided social amenities. Proper attention should be given to this sector, as it is an essential component of a growth strategy of an economy that is largely agrarian. In economies where the large majority of poor people live in rural areas, policies intended to reduce poverty should focus on improving the agricultural sector. Agriculture not only is a major component of such economies but its performance also affects other sectors. Past policies have capitalized on using agricultural growth as an engine of overall economic growth; however, a well-rounded development strategy should also focus on making the sector among the beneficiaries of that overall growth process.

This study argues that the grave problems faced by agrarian households in Ethiopia can be mitigated through appropriate socio-economic policies that favor peasant agriculture. In this study I argue and show that investment in rural infrastructure, social services, agricultural extension, and institutional improvement contribute to increased agricultural output, and increased efficiency, which helps ameliorate rural poverty.

Agriculture in Ethiopia uses little modern inputs and output per hectare is comparatively low. With a rapidly growing rural population, land holdings have been increasingly fragmented, resulting in a large proportion of small land holdings, each with little capital investment. Although fertilizer is the most widely used modern input, application rates are still among the lowest in the world. Use of improved seeds and pesticides is almost nonexistent while a large proportion of farmers reported damages due to crop diseases and other factors. A large majority of farmers do not apply the methods recommended by national extension programs. In a country subjected to frequent and widespread drought, only about 1 percent of the land is irrigated. Household data indicates that subsistence farmers are especially vulnerable to a shortage rainfall and frequently occurring droughts. In a country with ample water resources and where 85 percent of the population is engaged in rain-fed agriculture, which has become increasingly risky due to persistent drought, will be key to improving the lives of most Ethiopians.

This study used panel data from Ethiopian Rural Household Surveys conducted between 1994 and 2004 to indicate sources of output growth and technical efficiency in subsistence agriculture in Ethiopia. The results indicate that Ethiopian agriculture relies heavily on traditional factors of production, and crop output in Ethiopia is especially sensitive to changes in the amount of these traditional inputs. Specifically, the magnitude of the elasticity of output with respect to changes in rainfall suggests that the government and concerned agencies, in collaboration with farmers, should put a premium on finding ways to reduce the shocks faced during periods of low rainfall. Moreover, increased output gains from increase in cultivated area cannot be sustained given the fact that land size has been increasingly fragmented as a result of an ever-increasing rural population.

On average, the elasticity of output with respect to fertilizer application was one of the lowest. Segmenting the households to include only those that apply fertilizer indicates that the elasticity is one of the highest among all the measured inputs, pointing to potentially significant output gains from increased application of fertilizer among those that already use fertilizer and for its introduction to areas that currently do not use fertilizer. The results also indicate that each of the agro-ecological zones had gained from neutral technological improvements during the entire period. Given that gains in yield levels were sizable while modern input application rates changed little further inquiry into the sources of technological improvements is imperative. Assessing the factors that constrain the adoption of modern inputs, I find indicate that labor bottlenecks and a shortage of ploughing oxen lead to low levels of adoption and application of these inputs. Illiterate farmers are also less likely to adopt, while farmers cultivating fewer plots per household or per working member are more likely to adopt and apply larger quantities of these inputs. There is a complex relationship between the uptake of modern inputs on the one hand, and the number of agricultural extension agents in a particular peasant association, on the other. While, *on average*, the adoption of modern inputs is unaffected by the number agricultural extension agents in the peasant associations, farmers residing in peasant associations that already have infrastructure such as a peasant association center are more likely to adopt modern inputs. This suggests that the authorities should work towards developing extension support systems in areas where they are nonexistent. Moreover, to spur the use of use of inputs such as fertilizer requires, among other things, the introduction of simple agricultural machinery that help alleviate labor bottlenecks or facilitate the provision of credit that will help farmers acquire ploughing oxen and other inputs.

Taking the empirical findings of this study to a policy conclusion, I classify the options for increasing farm output and reducing farmer inefficiency into three major categories:

- Improvement in agricultural technology: this including, but not limited to, increased access by farmers to agricultural extension, investment in agricultural R & D to produce technology that is appropriate and less expensive than a pair of oxen, promote and foster the use and production of modern inputs and implements, and allocate sufficient budget to institutions that are engaged in these activities.

- Empowerment of rural institutions: including increased attention to rural institutions that promote efficient input and output markets,[57] appropriate land policy, and institutions that promote rural welfare enabling them to have better access to health, education, clean water, and other social services.

[57] IFPRI's Ethiopian Strategy Support Program, in collaboration with Ethiopian government, has launched a project to help facilitate input-output marketing and provide pricing information for farmers, which is an encouraging improvement in this direction.

- Improved infrastructure: in general well paved roads are rare in rural Ethiopia making it difficult to sell and purchase agricultural outputs and inputs, the same is true for other infrastructure. Improved access to health facilities, credit, and most importantly irrigation schemes help improve output growth and reduce inefficiency.

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Appendices

Appendix 2.A.1 Sections included in the agriculture part of Survey Round one, 1994

Survey Section	
Number	Detail
1	Land and its use
2	Inputs – for households who are not share tenants
3	Inputs- for share tenants
4	Crop output and sales-Meher
5	Crop output and sales-Belg
6	Recall on Previous harvests
7	Land rented to other households
8	Livestock ownership
9	Recall on livestock ownership
10	Livestock expenditure and income.

Source: Ethiopian Rural Household Survey, round one.

Appendix 2.A.2 Sections included in the agriculture part of Survey Round three, 1995

Survey Section	
Number	Detail
1	Land and its use
2	Crop output and sales
3	Labor input and other input expenditures
4	Livestock changes since last visit
5	Livestock expenditure and income
6	Events during the last Kiremt season

Source: Ethiopian Rural Household Survey, round three.

Appendix 2.A.3 Sections included in the agriculture part of Survey Round four, 1997

Survey Section	
Number	Detail
1	Land and its use
1.A	Quality of Land and Crops grown
1.B	Acquisition and Rights
1.C	Trees and Chat
2	Crop output and sales: Meher
3	Crop output and sales: Belg.
4	Agricultural input expenditures
5	Livestock ownership
6	Livestock expenditure and income
7	Labor
8	Events during the last Kiremt season
9	Events during the last Belg season

Source: Ethiopian Rural Household Survey, round four.

Appendix 2.A.4 Sections included in the agriculture part of Survey Round five, 1999

Survey Section	
Number	Detail
1	Land and its use: Quality of Land and Crops grown
2	Crop output and sales-Meher
3	Crop output and sales-Belg
4	Agricultural inputs expenditures
5	Livestock ownership
6	Livestock income and expenditure
7	Labor input
8	Events during the last Kiremt season
9	Events during the last Belg season
10	Innovation – crop adoption
11	Innovation – improved livestock
12	Innovation – Use of modern inputs.

Source: Ethiopian Rural Household Survey, round five.

Appendix 2.A.5 Sections included in the agriculture part of Survey Round six, 2004

Survey Section	
Number	Detail
1	Land and its use
1.A	Land acquisition and Rights
1.B	Plot output and sales
1.C	Trees
2	Agricultural inputs
2.A	Labor sharing
2.B	Other labor
2.C	Other expenditure.
3	Agricultural practices and technology.
4	Livestock ownership
5	Livestock expenditure and income
6	Events during the last Kiremt season
7	Events during the last Belg season

Source: Ethiopian Rural Household Survey, round six.

Appendix 4.A

The partial derivatives of equation (3.28) with respect to the parameters in the reparameterized set $\Theta = (\beta', \delta', \sigma^2, \gamma)'$ are:

$$\frac{\partial L(.)}{\partial \beta} = \sum_i \sum_t \left\{ \frac{Y_{ht} - f(X_{ht}, \beta) + Z_{ht}\delta}{\sigma^2} + \frac{\phi(\tilde{\mu}_{ht}^*)}{\Phi(\tilde{\mu}_{ht}^*)} \bullet \frac{\gamma}{\sigma_*} \right\} \bullet X_{ht}^*$$

where by $\phi(.)$ represents the density function of a standard normal variable. Also we have:

$$\frac{\partial L(.)}{\partial \delta} = -\sum_h \sum_t \left\{ \frac{Y_{ht} - f(X_{ht}, \beta) + Z_{ht}\delta}{\sigma^2} + \left[\frac{\phi(\tilde{\mu}_{ht})}{\Phi(\tilde{\mu}_{ht})} \bullet \frac{1}{(\gamma\sigma^2)^{1/2}} - \frac{\phi(\tilde{\mu}_{ht}^*)}{\Phi(\tilde{\mu}_{ht}^*)} \bullet \frac{(1-\gamma)}{\sigma_*} \right] \right\} \bullet Z_{ht}^*$$

$$\frac{\partial L(.)}{\partial \sigma^2} = -\frac{1}{2\sigma^2} \left\{ \sum_h (t_h) - \sum_h \sum_t \left[\frac{\phi(\tilde{\mu}_{ht})}{\Phi(\tilde{\mu}_{ht})} \bullet \tilde{\mu}_{ht} - \frac{\phi(\tilde{\mu}_{ht}^*)}{\Phi(\tilde{\mu}_{ht}^*)} \bullet \tilde{\mu}_{ht}^* \right] - \sum_h \sum_t \frac{Y_{ht} - f(X_{ht}, \beta) + Z_{ht}\delta}{\sigma^2} \right\}$$

$$\frac{\partial L(.)}{\partial \gamma} = \sum_h \sum_t \left\{ \frac{\phi(\tilde{\mu}_{ht})}{\Phi(\tilde{\mu}_{ht})} \bullet \frac{\tilde{\mu}_{ht}}{2\gamma} + \frac{\phi(\tilde{\mu}_{ht}^*)}{\Phi(\tilde{\mu}_{ht}^*)} \left[\frac{Y_{ht} - f(X_{ht}, \beta) + Z_{ht}\delta}{\sigma_*} + \frac{\tilde{\mu}_{ht}^* \bullet (1-2\gamma)}{2\gamma \bullet (1-\gamma) \bullet \sigma_*^2} \right] \right\}$$

where by:

$\tilde{\mu}_{ht} = {}^{Z_{ht}\delta}\!/\!_{\sigma_u} = {}^{Z_{ht}\delta}\!/\!_{(\gamma\sigma^2)^{1/2}}$;

$\tilde{\mu}_{ht}^* = \mu_{ht}^* / \sigma_* = \mu_{ht}^* / [\gamma(1-\gamma)\sigma^2]^{1/2}$ where $\mu_{ht}^* = (1-\gamma) Z_{ht}\delta - \gamma(Y_{ht} - f(X_{ht}, \beta))$

$\sigma_* = (\sigma_u \bullet \sigma_v) / \sigma = \left[\gamma(1-\gamma)\sigma^2\right]^{1/2}$

Appendix 4.B Pearson's correlation coefficients of selected variables used in the analysis

Variable	Value of output	Area	Labor	Oxen	Land quality	Rainfall	Education	Household size	Livestock units	Distance to PA center	Fertilizer use	Participated in NEP
Area	0.08*											
Labor	0.06*	0.13*										
Oxen	0.06*	0.35*	0.17*									
Land quality	-0.03**	-0.1*	-0.05*	-0.09								
Rainfall	0.014	-0.01	0.05*	0.02	-0.2							
Education	0.01	-0.01	-0.04*	0.01	-0.05*	0.04*						
Household size	0.038*	0.12*	0.58*	0.16*	-0.03*	0.03*	0.01*					
Livestock units	0.05*	0.44*	0.21*	0.51*	-0.08*	-0.12*	0.01	0.26*				
Distance to PA center	-0.05*	-0.02	-0.11*	-0.06*	0.19*	-0.23*	-0.07*	-0.12*	-0.04*			
Fertilizer use	0.08*	0.27*	0.17*	0.32*	-0.12*	-0.09*	0.03**	0.13*	0.35*	-0.16*		
Participated in NEP	0.01	-0.02	0.02	0.02	-0.04**	0.02*	0.05*	0.08*	0.04**	-0.08*	0.05*	
Number of extension offices	0.00	0.08*	-0.07*	0.05*	0.02	-0.15*	-0.08*	-0.098	0.09*	0.31*	0.08*	-0.04*

Note: Correlation coefficients with * and ** are significant at 1 and 5 percent of level of significance, respectively.

Appendix 4.C Maximum likelihood estimates of parameters associated with agricultural inputs included in the separate production frontiers for agroecological zones covered in ERHS

Variable	Northern Highlands		Central Highlands		Arussi/Bale		Hararghe		Enset	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Constant	0.164	0.168	4.014*	7.693	-5.684*	-5.148	-17.119*	-16.747	-11.569*	-10.144
Area of cultivated land	0.437*	7.742	0.209*	9.514	0.228*	4.902	0.228*	3.837	0.203*	8.779
Household members 16 years of age and older	0.072***	1.924	0.102**	2.043	0.374*	4.023	0.170**	2.495	0.115*	3.195
Level of education	0.135	1.084	0.036	0.65	0.252**	2.115	0.169**	2.506	0.069	1.056
Amount of rainfall 12 months before the survey	1.140*	7.554	0.418*	6.034	1.794*	11.025	3.583*	23.79	2.797*	16.561
Amount of Fertilizer used	0.003*	5.146	0.002*	10.235	0.004*	4.111	0.004*	6.419	0.002*	6.005
Number of ploughing oxen	0.152**	2.116	0.110*	4.325	0.092**	1.628	0.084**	1.968	0.054***	1.731
Average land quality	-0.061*	-2.908	-0.106*	-5.928	0.086**	1.832	-0.023	-0.672	-0.047***	-1.886
Number of hoes used	0.126*	2.821	0.03	1.411	0.064	1.377	0.0688**	1.878	0.043	1.474
Number of ploughs used	0.124*	2.919	0.068*	3.436	0.078	1.326	0.013	0.194	0.050**	2.074
Participated in New extension program	-0.159	-1.485	0.208**	2.435	-0.176	-0.708	-0.04	-0.275	-0.029	-0.233

Note: Parameter estimates with *, **, and *** are significant at 1, 5, and 10 percent levels of significance, respectively.

Appendix 4.D Maximum likelihood estimates of time and peasant association dummy variables included in the separate production frontiers estimated for agroecological zones covered in ERHS

Variable	Northern Highlands		Central Highlands		Arussi/Bale		Hararghe		Enset	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
1995dummy	-0.381*	-2.957	0.492*	5.882	0.035	0.217	0.05	0.409	-0.154***	-1.74
1997dummy	-0.308**	-2.166	0.201*	2.68	0.4	1.071	-0.311*	-2.698	0.167***	1.779
1999dummy	0.017	0.13	0.153**	2.013	-0.06	-0.148	-0.269*	-2.365	0.566*	6.763
2004dummy	0.132	1.059	0.334*	4.598	1.285*	3.167	1.316*	10.529	0.03	0.378
Geblen	-0.032	-0.322								
Shumsheha	-0.048	-0.551								
Debre Birhan			0.552*	8.364						
Yetemen			0.844*	9.675						
Turufe ketchema			1.158*	11.996						
Korodegaga					-0.123	-0.348				
Aze-Deboa									-0.123	-1.611
Adado									0.049	0.543
Gara-Godo									-1.322*	-11.183
Do'oma									0.702*	5.408

Note: Parameter estimates with *, **, and *** are significant at 1, 5, and 10 percent levels of significance, respectively.

Appendix 4.E Maximum likelihood estimates of the separate inefficiency equations for agroecological zones covered in ERHS

Variable	Northern Highlands		Central Highlands		Arussi/Bale		Hararghe		Enset	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Constant	-3.57	-1.56	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
Sex	-1.07	-1.52	-3.91*	-4.52	-11.09*	-9.03	-4.19*	-3.88	-3.20*	-3.28
Age	0.03***	1.93	-0.01	-0.98	-0.18*	-6.26	-0.02	-0.59	0.00	0.08
Level of education	1.26	1.43	-0.35	-0.71	-1.48	-1.50	0.13	0.14	-1.58*	-2.18
Female dummy	-0.10	-0.12	7.02*	7.33	0.46	0.34	-1.44	-1.40	6.09*	6.11
Household size	0.44*	3.11	-0.04	-0.35	0.25	1.49	0.38*	2.63	-0.42*	-4.06
Number of plots* log of cultivated area	0.39*	4.01	-0.22*	-3.58	0.46*	5.30	-0.56*	-4.77	-0.16*	-4.59
Cultivated area/ number of members 16 years and older	-0.01	-1.09	-1.38**	-2.38	-15.04*	-17.53	-14.05*	-7.96	0.00	-0.51
Oxen dummy	1.22	1.49	1.62*	2.65	-1.84***	-1.91	1.45	1.42	-2.26*	-3.13
Livestock units	-1.56*	-10.18	-0.05	-1.15	-1.27*	-14.78	-1.33*	-8.01	-0.08*	-3.10
Number of agricultural extension offices in PA	18.94*	4.69	-5.50*	-3.75	-1.61	-0.52	-7.53*	-9.16	2.00*	2.69
Crop affected by drought	4.37*	4.90	1.63	1.81	20.83*	11.94	5.20*	4.59	-0.12	-0.12
Survey month	-16.16*	-17.37	12.74*	17.36	-13.83*	-6.40	0.28	0.28	-0.16	-0.15
Elevation	0.00	0.91	0.00*	-6.94	-0.01*	-7.50	0.00	1.33	0.00*	-2.69
Distance to health center	-0.14*	-4.73	-0.15*	-5.44	-0.36*	-6.49	0.34	0.40	0.30*	8.95
Distance to closest market	-0.22*	-4.88	0.01	0.47	0.39*	5.49	-1.42	-1.48	-2.05*	-7.35
Distance to nearest PA center	0.26*	6.20	0.04	1.16	-0.01	-0.14	1.35	1.62	2.06*	4.75
Distance to cooperatives office	-0.40*	-8.36	0.00	0.08	0.82*	5.70	-0.13**	-2.31	-0.25*	-3.25
Sigma-squared	37.31*	17.32	36.93*	29.78	72.67*	13.34	19.97*	8.16	45.81*	30.35
Gamma	0.99*	999	0.99*	1973	0.99*	884	1.00*	1018	0.99*	1917
Sigma-squared V	0.26		0.22		0.55		0.08		0.25	
Sigma-squared U	37.05		36.71		72.12		19.89		45.56	
Log likelihood	-2433.94		-3157.43		-1745.75		-583.21		-3436.02	

Note: Parameter estimates with *, **, and *** are significant at 1, 5, and 10 percent levels of significance, respectively.

Appendix 4.F Maximum likelihood estimates of time and agroecology zone dummy variables included in the separate inefficiency equations

Agroecological Zone	PA	Variable	Year 1994	1995	1997	1999	2004
Northern Highlands	Haresaw	Coefficient	--	-4.31*	-2.58	6.3*0	1.87**8
		t-ratio	--	-4.25	-2.31	4.99	1.58
	Geblen	Coefficient	-1.15	-1.80***	-1.84***	3.39**	-0.72
		t-ratio	-1.14	-1.66	-1.66	2.03	-0.52
	Shumsheha	Coefficient	-0.92	-3.53*	-3.28*	4.10*	0.33
		t-ratio	-0.92	-3.21	-2.96	2.57	0.21
Central Highlands	Dinki	Coefficient	--	21.92*	-3.75*	-24.02*	-24.98*
		t-ratio	--	21.09	-2.45	-4.42	-4.75
	Debre Birhan	Coefficient	-1.95	26.66*	5.19	-28.56*	-28.96*
		t-ratio	-0.48	7.26	1.37	-5.44	-5.95
	Yetemen	Coefficient	-18.34*	-20.40*	-35.18*	-26.28*	-23.14*
		t-ratio	-8.14	-6.77	-9.58	-5.18	-2.74
	Turufe ketchema	Coefficient	5.54*	2.79	-8.57*	1.97***	-11.50*
		t-ratio	4.74	1.42	-5.04	1.73	-7.22
Arussi/Bale	Sirbana Godeti	Coefficient	--	-0.471	-3.212*	-1.353	-7.337*
		t-ratio	--	-0.443	-3.265	-1.385	-5.450
	Korodegaga	Coefficient	4.534*	4.017*	9.378*	-4.826*	-0.087
		t-ratio	4.271	4.052	8.656	-4.273	-0.080
Hararghe	Adele Keke	Coefficient	--	1.234	4.229*	-0.470	1.386
		t-ratio	--	1.155	3.719	-0.522	1.323
Enset	Imdibir	Coefficient	--	-4.63*	13.88*	-2.92*	-4.16*
		t-ratio	--	-3.49	10.88	-2.58	-3.91
	Aze-Deboa	Coefficient	-2.50***	-5.63*	6.50*	-4.23*	-3.93*
		t-ratio	-1.91	-3.94	2.67	-3.66	-3.53
	Adado	Coefficient	-3.62*	16.16*	10.50*	23.50*	-1.70
		t-ratio	-4.39	8.76	8.54	16.72	-1.46
	Gara-Godo	Coefficient	12.11*	14.37*	0.84	-2.45*	-21.80*
		t-ratio	7.39	8.79	0.82	-1.90	-15.72
	Do'oma	Coefficient	7.58*	18.33*	18.10*	-3.69*	-38.03*
		t-ratio	4.80	10.50	7.68	-3.64	-8.67

Note: Parameter estimates with *, **, and *** are significant at 1, 5, and 10 percent levels of significance, respectively.

Appendix 4.G Average zone level inputs uses and value of output in the zones included in Ethiopian Rural Household Surveys

Agroecological Zone	Year	Real value of output	Area of cultivated land	Number of members 16 years of age and older	Amount of Fertilizer used	Number of ploughing oxen	Amount of rainfall	Agricultural extension officers in PA	Livestock units	Participated in New extension program	Crop affected by drought	Average land quality
Northern Highlands	1994	850	1	2.5	1	0.9	577	1	1.7	0	0.4	3.5
	1995	866	1	2.5	0	1.1	840	1	1.7	0	0.3	3.4
	1997	1064	1.2	2.9	5	1.4	813	1	2.6	0	0	3.2
	1999	1086	0.7	2.6	6	1.6	586	1	2.8	0.1	0	3.4
	2004	1198	0.6	2.4	1	0.8	569	1	2.2	0	0	3.4
Central Highlands	1994	1104	1.6	3.2	68	1.6	1088	0.6	4.5	0.1	0.1	2.3
	1995	1259	1.6	3.2	68	1.5	1048	0.6	4	0	0	2.2
	1997	1761	2.8	3.8	72	1.8	1071	0.6	5.1	0	0	2
	1999	1904	1.2	3	95	1.8	997	0.9	4.6	0.1	0	2
	2004	1793	1.3	2.6	49	1.1	1064	0.9	4.4	0	0	2.2
Arussi/Bale	1994	906	2.2	3.4	76	1.7	871	1	3.9	0.1	0.2	1.6
	1995	892	2	3.5	138	1.6	782	1	3.8	0	0.3	1.7
	1997	1835	2.5	4.8	142	2.3	891	1	4.7	0	0	1.4
	1999	1024	1.8	3.1	97	2.1	939	1.5	4.2	0	0	1.5
	2004	1565	1.5	3.2	78	1.4	960	1.4	3.9	0.1	0	1.6
Hararghe	1994	1303	1.1	3.2	36	1.2	523	1	1.4	0	0.8	2.8
	1995	1511	1.2	3.1	4	1.1	972	1	1.3	0.1	0.1	2.5
	1997	2240	1.6	3.8	35	1.1	982	1	1.9	0.1	0	2.2
	1999	2129	0.7	3.1	42	1.2	710	1	1.8	0.1	0	2.3
	2004	1944	1.4	2.8	29	0.8	880	1	1.7	0.1	0	1.6
Enset	1994	980	0.5	3.8	18	1.2	1051	0.4	1.3	0	0.3	2.4
	1995	1004	0.6	3.7	8	1.2	1186	0.4	1.4	0	0.1	2.2
	1997	1421	1.2	4.3	12	1.8	1313	0.4	1.7	0.1	0	2
	1999	1695	0.3	3.4	11	0.6	1214	0.4	1.5	0.2	0	1.8
	2004	1754	0.6	2.8	2	0.4	1072	0.4	1.9	0.1	0	1.9

Appendix 4.H Maximum likelihood estimates parameters associated with agricultural inputs included in the stochastic production frontier that uses per hectare values

Variable	Coefficient	t-ratio
Constant	3.953*	29.607
Household members 16 years of age and above per hectare	0.178*	10.908
Level of education	0.003**	2.375
Amount of rainfall 12 months before the survey per hectare	0.456*	22.710
Amount of Fertilizer used per hectare	0.000**	-0.209
Number of ploughing oxen per hectare	-0.001	-1.026
Average land quality	0.001***	1.833
Number of hoes used per hectare	0.001	1.623
Number of ploughs used per hectare	0.001	0.372
Participated in New extension program	0.001	0.584

Note: Parameter estimates with *, **, and *** are significant at 1, 5, and 10 percent levels of significance, respectively.

Appendix 4.I Maximum likelihood estimates of time and agroecologic zone dummy variables included in the stochastic production frontier that uses per hectare values

Variable	Coefficient	t-ratio
1995dummy	0.401*	7.118
1997dummy	0.187*	3.559
1999dummy	0.244*	5.007
2004dummy	0.129*	2.585
Central Highlands	0.658*	14.609
Arussi/Bale	0.978*	19.325
Hararghe	0.851*	12.602
Enset	1.073*	19.230

Note: All parameter estimates are significant at 1 percent level of significance.

Appendix 4.J Maximum likelihood estimates of the inefficiency equation associated with the production frontier that uses per hectare values

Variable	Coefficient	t-ratio
Constant	3.09*	2.50
Sex	-1.85*	-3.23
Age	0.02**	2.05
Level of education	-1.46*	-3.04
Female dummy	4.21*	5.05
Household size	-0.28*	-4.21
Number of plots* log of cultivated area	-0.19*	-5.09
Cultivated area/ number of members 16 years and older	-0.02*	-7.37
Oxen dummy	-2.94*	-4.39
Livestock units	-0.29*	-11.12
Number of agricultural extension offices in peasant association	-1.81*	-4.71
Crop affected by drought	1.41**	2.22
Survey month	7.79*	15.80
Elevation	-0.01*	-12.86
Distance to health center	0.09*	9.68
Distance to closest market	-0.14*	-9.55
Distance to nearest PA center	0.13*	10.49
Distance to cooperatives office	-0.13*	-7.33
Sigma-squared	44.99*	39.42
Gamma	0.99*	2459.30
Sigma-squared V	0.36	
Sigma-squared U	44.63	
Log likelihood	-12191.85	

Note: All estimates are significant at 1 percent level, except the one associated with age and the variable associated with drought, which are significant at 5 and 10 percent, respectively.

Appendix 4.K Maximum likelihood estimates of period-agroecologic zone dummy variables included in the inefficiency equation associated with the production frontier using per hectare values

Agroecological Zone	Variable	Year				
		1994	1995	1997	1999	2004
Northern Highlands	Coefficient	--	21.60*	-12.53*	-40.38*	-40.96*
	t-ratio	--	27.23	-10.32	-40.41	-43.00
Central Highlands	Coefficient	-5.96*	16.02*	-1.76	-28.25*	-28.95*
	t-ratio	-4.43	12.54	-1.37	-23.04	-25.65
Arussi/Bale	Coefficient	-10.66*	4.22**	-25.09*	-14.75*	-20.09*
	t-ratio	-5.65	2.45	-12.75	-7.85	-9.82
Hararghe	Coefficient	-16.25*	-13.44*	-5.61**	-33.42*	-31.42*
	t-ratio	-4.75	-4.40	-1.84	-14.67	-14.37
Enset	Coefficient	2.47	9.16*	0.05	-1.83	-24.30*
	t-ratio	1.63	5.96	0.03	-1.23	-15.64

Note: All estimates are significant at 1 percent level except one with a superscript of A which is significant at 5 percent four with a superscript of B which are not significant.

Appendix 4.L Maximum likelihood estimates of parameters associated with agricultural inputs included in the stochastic production frontier estimated to test the inverse relationship between farming efficiency and farm size

Variable	Coefficient	t-ratio
Constant	4.53	12.85
Area of cultivated land	-3.61	-3.94
Area of cultivated land Squared	1.91	4.17
Household members 16 years of age and above	0.11	4.93
Level of education	0.15	4.01
Amount of rainfall 12 months before the survey	0.36	6.88
Amount of Fertilizer used	0.00	12.38
Number of ploughing oxen	0.13	6.95
Average land quality	-0.09	-8.63
Number of hoes used	0.10	5.44
Number of ploughs used	0.07	4.14
Participated in New extension program	0.16	2.69

Note: All parameter estimates are significant at 1 percent level of significance

Appendix 4.M Maximum likelihood estimates of time and agroecologic zone dummy variables included in the stochastic production frontier estimated to test the inverse relationship between farming efficiency and farm size

Variable	Coefficient	t-ratio
1995dummy	0.27	5.00
1997dummy	0.11[A]	2.02
1999dummy	0.03 [B]	0.54
2004dummy	0.16	3.45
Central Highlands	0.38	7.34
Arussi/Bale	0.50	8.20
Hararghe	0.74	11.16
Enset	1.08	17.75

Note: All parameter estimates are significant at 1 percent level except those with superscripts A and B, which are significant at 5 percent level and not significant, respectively.

Appendix 4.N Maximum likelihood estimates of the inefficiency equation associated with the production frontier that tests the efficiency-farm size relationship

Variable	Coefficient	t-ratio
Constant	2.47**	2.22
Sex	-1.83*	-3.18
Age	0.02**	2.07
Level of education	-0.83**	-2.02
Female dummy	4.51*	5.39
Household size	-0.24*	-4.21
Number of plots* log of cultivated area	-0.15*	-3.62
Cultivated area/ number of members 16 years and older	-0.02*	-4.33
Oxen dummy	-0.82***	-1.71
Livestock units	-0.27*	-8.64
Number of agricultural extension officers in peasant association	-1.99*	-4.8
Crop affected by drought	1.60*	2.79
Survey month	8.31*	16.92
Elevation	-0.01*	-14.18
Distance to health center	0.07*	7.84
Distance to closest market	-0.12*	-9.28
Distance to nearest PA center	0.13*	10.88
Distance to cooperatives office	-0.14*	-7.8
Area of cultivated land	-0.25	-1.44
Sigma-squared	44.74*	42.74
Gamma	0.99*	3098.86
Sigma-squared V	0.291	
Sigma-squared U	44.449	
Log likelihood	-11955.89	

Note: Parameter estimates with *, **, and *** are significant at 1, 5, and 10 percent levels of significance, respectively.

Appendix 4.O Maximum likelihood estimates of time-zone dummy variables in the inefficiency equation associated with the production frontier that tests the inverse relationship between efficiency and farm size

Agroecological Zone	Variable	Year				
		1994	1995	1997	1999	2004
Northern Highlands	Coefficient	--	21.88	-13.26	-42.26	-42.23
	t-ratio	--	29.46	-12.51	-46.17	-43.91
Central Highlands	Coefficient	-8.28	15.32	-4.23	-30.62	-30.86
	t-ratio	-5.78	12.42	-3.43	-26.02	-25.92
Arussi/Bale	Coefficient	-14.63	3.6[A]	-27.4	-22.14	-22.82
	t-ratio	-8.89	2.34	-16.56	-13.87	-12.9
Hararghe	Coefficient	-18.14	-21.94	-12.87	-34.74	-32.89
	t-ratio	-5.92	-6.23	-3.76	-19.94	-17.7
Enset	Coefficient	4.26	9.75	0.69 [B]	-1.14 [B]	-20.25
	t-ratio	2.93	6.59	0.47	-0.78	-12.71

Note: All parameter estimates are significant at 1 percent level except those with superscripts A and B, which are significant at 5 percent level and not significant, respectively.

Appendix 4.P Maximum likelihood estimates of parameters associated with agricultural inputs included in the stochastic production frontier that uses the log-linear specification

Variable	Coefficient	t-ratio
Constant	5.010*	12.634
Area of cultivated land	0.578*	10.875
Household members 16 years of age and above	-0.010	-0.149
Level of education	-0.010	-0.074
Amount of rainfall 12 months before the survey	0.258*	4.549
Amount of Fertilizer used	0.004*	6.028
Number of ploughing oxen	0.1398*	2.380
Average land quality	-0.044	-1.062
Number of hoes used	0.070	1.426
Number of ploughs used	0.202*	4.246
Participated in New extension program	0.595*	3.364

Note: parameter estimates with * are significant at 1percent of level of significance.

Appendix 4.Q Maximum likelihood estimates of parameters associated with the squared terms of agricultural inputs included in the stochastic production frontier that uses the log-linear specification

Variable	Coefficient	t-ratio
Area of cultivated land squared	0.051*	6.475
Household members 16 years of age and older squared	0.014*	2.150
Amount of Fertilizer used squared	0.000*	-3.844
Number of ploughing oxen squared	0.017	1.515
Average land quality squared	-0.010*	-2.120
Number of hoes used squared	-0.003*	-1.723
Number of ploughs used squared	-0.005*	-2.350

Note: Parameter estimates with * are significant at 1percent of level of significance.

Appendix 4.R Maximum likelihood estimates of parameters of the interaction terms of variables included in the stochastic production frontier that uses the log-linear specification

Variable	Coefficient	t-ratio
Cultivated area* HH members 16 years and above	-0.117*	-4.606
Cultivated area*level of education	-0.027	-0.777
Cultivated area* amount of fertilizer used	0.000	-0.257
Cultivated area*number of ploughing oxen	-0.022	-1.048
Cultivated area*average land quality	-0.019	-1.558
Cultivated area*number of hoes used	-0.062*	-3.291
Cultivated area*number of ploughs used	0.002	0.122
Cultivated area*participated in new extension program	0.124**	2.423
HH members 16 years and above*level of education	-0.027	-0.407
HH members 16 years and above* amount of fertilizer used	0.000	-1.038
HH members 16 years and above*number of ploughing oxen	-0.011	-0.342
HH members 16 years and above*average land quality	0.017	0.838
HH members 16 years and above*number of hoes used	0.076*	3.368
HH members 16 years and above*number of ploughs used	0.044**	1.705
HH members 16 years and above*participated in new extension program	-0.106	-0.945
Level of education* amount of fertilizer used	0.000	-0.632
Level of education*number of ploughing oxen	0.037	0.898
Level of education*average land quality	0.081**	2.554
Level of education*number of hoes used	0.053	1.583
Level of education*number of ploughs used	-0.039	-0.924
Level of education*participated in new extension program	-0.313**	-2.460
Amount of fertilizer used*number of ploughing oxen	0.000**	-2.194
Amount of fertilizer used*average land quality	0.000	-0.425
Amount of fertilizer used*number of hoes used	0.000	1.590
Amount of fertilizer used*number of ploughs used	0.000	-1.029
Amount of fertilizer used*participated in new extension program	-0.001	-1.038
Number of ploughing oxen*average land quality	0.000	-0.014
Number of ploughing oxen*number of hoes used	-0.007	-0.424
Number of ploughing oxen*number of ploughs used	-0.026	-1.557
Number of ploughing oxen*participated in new extension program	-0.107***	-1.752
Average land quality*number of hoes used	0.001	0.080
Average land quality*number of ploughs used	-0.010	-0.728
Average land quality*participated in new extension program	-0.004	-0.110
Number of hoes used*number of ploughs used	-0.048*	-6.743
Number of hoes used*participated in new extension program	0.058	0.876
Number of ploughs used*participated in new extension program	-0.083	-1.532

Note: Parameter estimates with *, **, and *** are significant at 1, 5, and 10 percents of levels of significance, respectively.

Appendix 4.S Maximum likelihood estimates of time and agroecologic zone dummy variables included in the stochastic production frontier that uses the log-linear specification

Variable	Coefficient	t-ratio
1995dummy	0.276	5.251
1997dummy	0.150	2.802
1999dummy	0.135	2.756
2004dummy	0.286	5.598
Central Highlands	0.304	5.545
Arussi/Bale	0.416	6.308
Hararghe	0.698	9.709
Enset	1.032	15.333

Note: All parameter estimates are significant at 1 percent of level of significance.

Appendix 4.T Maximum likelihood estimates of time-zone dummy variables in the inefficiency equation associated with the log-linear specification

Agroecological Zone	Variable	Year				
		1994	1995	1997	1999	2004
Northern Highlands	Coefficient	--	23.403	-12.968	-42.577	-42.482
	t-ratio	--	32.622	-11.611	-42.415	-37.870
Central Highlands	Coefficient	-7.379	18.284	-1.853 [B]	-30.212	-30.211
	t-ratio	-5.874	16.318	-1.621	-23.569	-27.530
Arussi/Bale	Coefficient	-12.299	6.864	-24.193	-18.226	-19.102
	t-ratio	-7.901	4.744	-13.597	-10.800	-11.032
Hararghe	Coefficient	-13.079	-18.618	-6.034 [A]	-30.246	-28.930
	t-ratio	-4.320	-5.771	-1.920	-17.535	-14.619
Enset	Coefficient	7.457	13.542	3.723	2.029 [B]	-20.287
	t-ratio	5.550	10.198	2.857	1.554	-12.740

Note: All parameter estimates are significant at 1 percent level except the one with a superscript of A, which is significant at 10 percent, two estimates with a superscript of B, which are not significant.

Appendix 3.U Maximum likelihood estimates of the inefficiency equation associated with the log-linear specification

Variable	Coefficient	t-ratio
Constant	-1.993***	-1.652
Sex	-1.594**	-2.235
Age	0.016	1.489
Level of education	-0.598	-1.025
Female dummy	4.097*	4.817
Household size	-0.201*	-2.938
Number of plots* log of cultivated area	-0.168*	-5.100
Cultivated area/ number of members 16 years and above	-0.013*	-3.759
Oxen dummy	-0.952	-1.610
Livestock units	-0.191*	-5.486
Number of agricultural extension offices in peasant association	-2.382*	-6.167
Crop affected by drought	1.840*	3.107
Survey month	9.327*	17.114
Elevation	-0.005*	-10.772
Distance to health center	0.071*	7.160
Distance to closest market	-0.152*	-11.253
Distance to nearest PA center	0.165*	15.390
Distance to cooperatives office	-0.177*	-10.882
Sigma-squared	45.997*	41.536
Gamma	0.994*	2947.810
Sigma-squared V	0.277	
Sigma-squared U	45.721	
Log likelihood	-17324.860	

Note: Estimates with *, **, and *** are significant at 1, 5, and 10 percent levels of significance, respectively

Appendix 4. V Ordinary least square estimates (OLS) the parameters of the Cobb-Douglas production function

Variable	Coefficient	t-ratio
Constant	3.687	3.584
Area of cultivated land	0.321	7.603
Household members 16 years and older	0.576	7.279
Level of education	0.298	2.363
Amount of rainfall 12 months before the survey	0.067[B]	0.426
Amount of Fertilizer used	0.007	12.270
Number of ploughing oxen	0.382	6.319
Average land quality	-0.279	-8.324
Number of hoes used	0.105	2.345
Number of ploughs used	0.018 [B]	0.428
Participated in New extension program	-0.011 [B]	-0.058
1995 dummy	-2.801	-19.202
1997dummy	0.308 [A]	2.047
1999dummy	0.954	6.300
2004dummy	1.898	12.562
Central Highlands	0.120 [B]	0.736
Arussi/Bale	0.999	5.283
Hararghe	1.179	5.219
Enset	0.977	5.911

Note: All parameter estimates are significant at 1 percent level except one with a superscript of A, which is significant at 5 percent, and those with superscript of B, which are not significant:

Appendix 4.W OLS estimates of the time-agroecologic zone dummy variables obtained by regressing residuals from OLS-Cobb-Douglas regression on factors that affect efficiency

Agroecological Zone	Variable	Year				
		1994	1995	1997	1999	2004
Northern Highlands	Coefficient	--	-0.77	1.99	2.68	2.13
	t-ratio	--	-2.58	6.31	8.16	6.69
Central Highlands	Coefficient	2.16	-1.26	1.88	2.41	2.37
	t-ratio	7.29	-4.19	6.16	7.80	7.74
Arussi/Bale	Coefficient	1.16	2.08	1.96	0.86	1.38
	t-ratio	3.28	5.96	5.33	2.31	3.59
Hararghe	Coefficient	2.20	3.33	1.57	1.37	1.64
	t-ratio	4.95	7.62	3.48	3.08	3.61
Enset	Coefficient	0.39A	2.59	0.71	1.20	1.30
	t-ratio	1.32	8.51	2.27	3.71	4.02

Note: All parameter estimates are significant at 1 percent level except the one with a superscript of A, which is not significant.

Appendix 4.X OLS estimates of regressing residuals from OLS-Cobb-Douglas regression on factors that affect efficiency

Variable	Coefficient	t-ratio
Constant	-5.414	-9.577
Sex	0.418*	3.205
Age	-0.004	-1.616
Level of education	-0.142	-1.187
Female dummy	-0.251	-1.423
Household size	0.012	0.691
Number of plots* log of cultivated area	-0.014	-1.507
Cultivated area/ number of members 16 years and older	0.005*	3.845
Oxen dummy	-0.185	-1.543
Livestock units	-0.027	-1.516
Number of agricultural extension agents in peasant association	0.128	1.450
Crop affected by drought	-0.384*	-2.306
Survey month	-1.556*	-12.043
Elevation	0.000*	9.837
Distance to health center	0.002	0.883
Distance to closest market	0.025*	9.952
Distance to nearest PA center	-0.018*	-8.873
Distance to cooperatives office	0.034*	8.562