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Upscaling the productivity performance of the Agricultural Commercialization Cluster Initiative in Ethiopia

An assessment using a farm household level model

Kamel Louhichi, Umed Temursho, Liesbeth Colen, Sergio Gomez y Paloma

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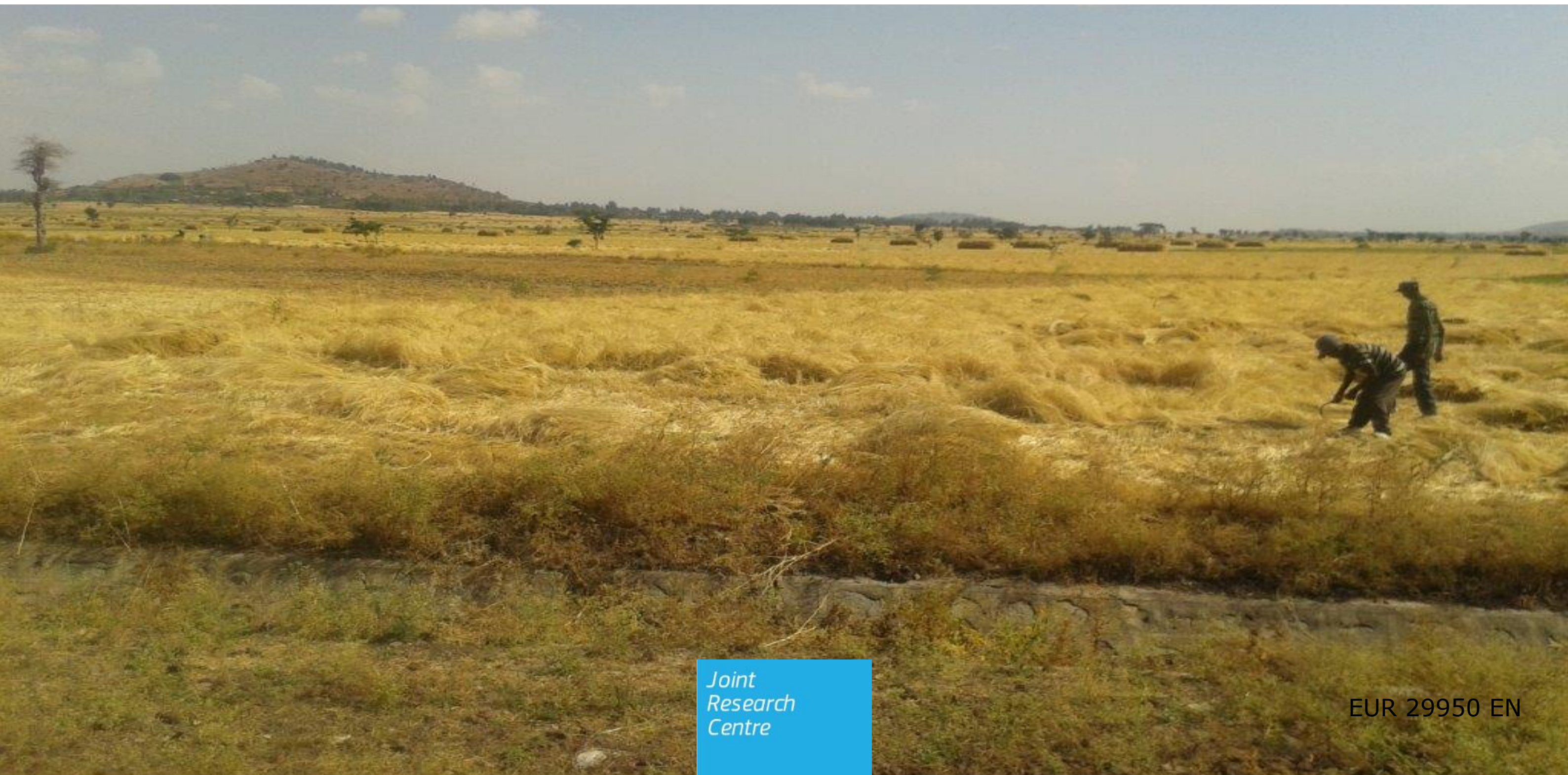

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Summary: This report presents the results of an impact analysis of several scenarios related to the Agricultural Commercialization Cluster Initiative introduced by the Government of Ethiopia during the first Growth and Transformation Plan (GTP I) as a mechanism to improve agricultural productivity and production within specific geographies targeting a limited number of high-value commodities. This analysis is achieved using a micro-economic model applied to a representative sample of 2,886 farm households spread throughout the country, taken from the Ethiopia Socioeconomic Survey. The potential effects of the simulated scenarios on land use, production, input use, farm income and some food security related indicators are presented and discussed.

UPSCALING THE PRODUCTIVITY PERFORMANCE OF THE AGRICULTURAL COMMERCIALIZATION CLUSTER INITIATIVE IN ETHIOPIA

An assessment using a farm household level model

TABLE OF CONTENTS

Abstract

The Agricultural Commercialization Cluster (ACC) initiative is one of the main policy interventions in the agricultural sector in Ethiopia. It was introduced during the first Growth and Transformation Plan (GTP I, 2010-2015) as a mechanism to integrate the Agricultural Transformation Agenda interventions along specific value chains for a limited number of priority (or high-value) commodities, across the four major agricultural regions of the country: Amhara, Oromia, SNNP and Tigray. According to the Agricultural Transformation Agency (ATA), the ACC initiative aims to increase farmers' income, facilitate market opportunities, enhance agro-processing services, increase the volume of products and create more jobs.

The Agricultural Commercialization Clusters are considered to play the role of Centres of Excellence and are being supported in expanding their production and productivity, and in integrating their commercialization activities. Therefore, these areas are meant to serve as 'models for learning' in the process of implementation of the ACC approach and scaling up of best practice across the country.

The main aim of this study is to analyze the impacts of this initiative on the performance and livelihood of smallholder farmers in Ethiopia. Specifically, we *ex ante* assess the impact of scaling up, to the respective regions of Ethiopia, the productivity performance achieved by the 'model farmers' in the areas (clusters) covered by the ACC initiative. This is accomplished using the farm household model FSSIM-Dev (Farm System Simulator for Developing Countries), which is applied to a representative sample of 2,886 individual farm households spread throughout the country, taken from the 2013/14 Ethiopia Socioeconomic Survey. Simulation results show that upscaling the ACC productivity performance to the respective regions would lead to an increase in production of the main products ranging between 1.8% and 62.6%, depending on scenario, region and commodity. The average country-level production increase (across all ACC scenarios considered) for wheat, teff, maize and barley are assessed to be 29.6%, 21.1%, 12.8% and 12.6%, respectively. These impacts are driven by rise in land productivity, rather than area expansion (through putting fallow land into cultivation) and/or area reallocation. The increase in crop yields would also have a positive impact on both income and poverty level of farm households. Across all scenarios at the country level, the average increase in gross income is assessed to be around 14%, and the reduction in poverty gap around 2.1%. The largest income change is experienced by farms specializing in field crops, which is not surprising as the ACC targeted crops considered are field crops, and in medium-large farms (i.e. farms with total production value of larger than ETB 9,000) in view of their high land productivity in comparison to small farms. At the individual farm household level, the average increase in gross income for all farms is assessed to be around 9%, although the impact could be more pronounced for individual farms: for example, 85% of the farms would experience an increase in gross income of up to 17% to 32%, depending on the nature of scenarios considered. The increase in both production and income would raise food consumption, and improve nutritional indicators such as the energy intake, protein intake and Healthy Food Diversity Index (HDFI) by 2.32%, 2.25% and 0.54%, respectively.

Foreword

The Joint Research Centre (JRC) is one of the Directorates-General (DGs) of the European Commission (EC); its objective is to provide independent scientific and technical support to EU policy. Since 2014, the JRC has been collaborating with the Directorate-General for International Cooperation and Development (DG DEVCO) under the Administrative Arrangement 'Technical and scientific support to agriculture and food and nutrition security sectors in sub-Saharan Africa' (TF4FNS), with the purpose of providing support for: i) improvement of information systems on agriculture, nutrition and food security; ii) policy and economic analysis to support the policy decision-making process; and iii) scientific advice on selected topics concerning sustainable agriculture and food and nutrition security.

Within this framework, the Economics of Agriculture (EoA) Unit of the JRC is committed to provide to the DG DEVCO and to the EU delegations micro-economic analysis in the areas of food and nutrition security and (sustainable) agriculture. This consists of developing quantitative economic tools and models for *ex ante* impact assessment of selected national agricultural policies and EU cooperation policies on food security and rural poverty alleviation in sub-Saharan Africa.

The Federal Democratic Republic of Ethiopia is one of the countries selected for running such policy analysis. The extensive discussion with the Delegation of the European Union to Ethiopia, the Ethiopian Ministry of Agriculture and Natural Resources, as well as researchers from various Ethiopian research institutes, led us to focus our analysis on quantifying the scaling effects of the Agricultural Commercialization Cluster Initiative. This initiative was introduced by the Ethiopian government during the first Growth and Transformation Plan (GTP I) as a mechanism to improve agricultural productivity and production for a limited number of priority (or high-value) commodities within specific geographies. This report presents the methodology, the data used and the main findings of this impact assessment, and attempts to provide policymakers in Ethiopia with some evidence on the potential impacts of this initiative at the level of the individual farm household, farm type, region and Federal State.

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The authors would like to thank their colleagues from the Delegation of the European Union to Ethiopia, especially Dominique Davoux (Head of Section, Rural Development), Dr Eshetu Mulatu and David Mogollon (former Head of Section, Rural Development), for their comments and advice throughout the process of the study, but also for their help and technical support during the authors' missions to Ethiopia.

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Disclaimer

1 Introduction

The Ethiopian economy remains dominated by agriculture. In recent years, this traditional sector has accounted for about 68% of employment and 34% of GDP, but is making up a decreasing fraction of output over time. More than 79 million people in Ethiopia rely on agriculture for their livelihoods (World Bank, 2018). While the economy has been growing at official rates of about 10% per year (e.g. between 2003 and 2016 real GDP grew by 7.7% per year), many people are still poor and food insecure. The poverty rate in 2015 was 26.7% (World Bank, 2018) and Ethiopia still ranks low on the Global Hunger Index (IFPRI, 2018). At the same time, it should be noted that there has been a remarkable improvement in poverty levels over the last fifteen years: back in the 1990s, two thirds of the Ethiopian population lived below the global poverty line of USD 1.90 in purchasing power parity (PPP), whereas national poverty lines suggested poverty rates of 46% in 1995 and 44% in 1999 (Dercon and Gollin, 2019).

Since the 1990s, agriculture has played and is still playing a central role in the Ethiopian government's policy goals and development strategies. The government's main development plans include the Sustainable Development and Poverty Reduction Plan (SDPRP) 2002-2005, the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) 2005-2010, and the Growth and Transformation Plans (GTP I and GTP II covering 2010-2015 and 2015-2020, respectively). The foundation of all these plans, especially of the SDPRP and PASDEP, was the Agricultural Development Led Industrialization (ADLI) strategy (Ministry of Planning and Economic Development, 1993). The specific development strategies set out in ADLI were: improving agricultural technologies, especially seeds; using modern inputs, including fertilizers and pesticides; expanding irrigation and infrastructure; and expanding rural non-agricultural opportunities and activities. Dercon and Gollin (2019) argue that such 'agriculture first' policies have intellectual roots in models such as Johnston and Mellor (1961), where productivity growth in agriculture stimulates growth in the non-agricultural sectors (see also Schultz, 1964). Generally, all these 'dual economy' models, pioneered by Lewis (1954) – a highly influential paper that 'bundles together theories of growth, structural transformation, inequality and distribution, wage determination, and population' (Gollin, 2014, p. 71) - suggest that investments or productivity growth in one sector (e.g. traditional sector) would drive a process of transformation and structural change and thus ultimately lead to overall growth of the entire economy.

It is widely accepted that Ethiopia's agricultural growth over the past decades has been central to the economic growth of the country. Official numbers indicate that the value of agricultural production in Ethiopia has more than doubled since 2000 (FAO, 2018). Growth has been attributed to expansion of land and labour use, as well as to the increased use of modern inputs and extension services (Cheru et al., 2019). Production of cereals in 2015/16 was recorded to be three times higher than that in 1995/96; over the same period, cultivated area and crop yields increased by 70% and 86%, respectively (CSA, 2018). Although the literature has raised questions about reliability/overestimation in these official figures (see e.g. Dercon and Zeitlin, 2009; Cochrane and Bekele, 2018), there is little doubt that agricultural productivity has been growing very fast over the past few decades.

However, use of modern inputs (including knowledge input) and productivity levels remain low, implying that there is potential for further productivity growth. For example, despite rapid growth in the use of fertilizer and improved seeds, current adoption rates remain quite low (Dercon and Gollin, 2019). Also, there is very limited development of irrigation in Ethiopia, although it is believed to contribute strongly to increasing agricultural production. Both Ethiopia's GTP I and GTP II have set clear targets on crop productivity shifts, use of agricultural inputs and water use for agriculture, and several policy interventions have been put in place to achieve these targets.

The Agricultural Commercialization Cluster (ACC) initiative is one of these policy interventions. It was introduced during the GTP I as a mechanism to integrate the Agricultural Transformation Agenda interventions along specific value chains for a limited number of priority (or high-value) commodities in high-potential areas, also known as geographic clusters, across the country. Briefly, the ACC initiative aims to enhance commercial opportunities for smallholder farmers, through expanding the quantity and quality of three interrelated agricultural inputs (chemical fertilizer, improved seeds, and extension and advisory services), and facilitating market linkages on the output side of smallholder farming 'business'.

The ACC initiative contains clearly defined geographic clusters specializing in priority commodities across the four major agricultural regions of the country: Amhara, Oromia, SNNP (Southern Nations, Nationalities, and Peoples), and Tigray. These clusters are considered to play the role of Centres of Excellence and are being supported in expanding their production and productivity, and in integrating their commercialization activities. Therefore, these areas are intended to serve as 'models for learning' in the process of implementation of the

ACC approach and of scaling up of best practice across the country (Section 5 provides detailed description, performance and theoretical analysis for the ACC interventions).

The objective of this study is to analyze the impacts of upscaling this initiative on the performance of smallholder farmers in Ethiopia, using the farm household model FSSIM-Dev (Farming System Simulator for Developing Countries). In particular, FSSIM-Dev is used to simulate the response of a representative sample of 2,886 individual farm households, taken from the 2013/14 Ethiopia Socioeconomic Survey, to introduction of the ACC-type initiative. More specifically, we assess several scenarios for scaling up, to the respective regions of Ethiopia, the productivity performance achieved by the 'model farmers' in the areas (clusters) covered by the ACC initiative.

In particular, the focus of this study is to assess the effects of productivity shifts in five commodities (maize, wheat, teff, barley and haricot beans) prioritized by the ACC initiative on land use, production, incomes, food consumption and nutrition of farm households in Ethiopia and in its four main agricultural regions of Amhara, Oromia, SNNP and Tigray. More concretely, we quantify the effects of an increase in yields, equivalent in size to the yield improvements achieved within the ACC areas, assuming that all farmers in the ACC-covered regions are able to perform as well as the model farmers (or cluster farmers) in their respective regions. Thus, the imposed productivity effects represent potential, not necessarily fully feasible, crop yield increases. By imposing region- and crop-specific exogenous yield shocks, we expect to take better account of the real possibilities of smallholder farmers having to deal with differences in local climate, soil quality, infrastructure availability, marketing conditions, etc. The empirical assessments in this study are also in line with the GTP II strategy, which states that one of the tracks to achieving the envisaged shifts in crop productivities is 'to raise the productivity level of the majority of farmers to the productivity level attained by model farmers' (National Planning Commission, 2016, p. 121). Our micro-level modelling approach also allows us to upscale the ACC productivity gains to different types of farms, according to e.g. farm specialization and farm economic size, and more generally examine the entire distribution of impacts across all farm households.

2 Agriculture and rural development in Ethiopia

2.1 The agricultural sector in Ethiopia

Agriculture is by far the most important sector in Ethiopia, as the majority of Ethiopians depend on agriculture for their livelihoods. Though the importance of agriculture in the overall economy is declining as services and more recently industries are growing, it remains a major source of employment. Almost 70% of employment is in the agricultural sector (World Bank, 2018).

Ethiopian agriculture is largely characterized by smallholder farming, which generates close to 94% of agricultural GDP. The remaining 5% comes from a relatively small number of (former) state-owned or private agricultural enterprises (commercial farms). Official statistics indicate that in 2016/2017, the agricultural sector employed 17.4 million farmers, who cultivated 12.6 million hectares of farmland (CSA, 2016/2017). This illustrates the minuscule size of Ethiopian farms, with average size of less than one hectare, as will be described in more detail later.

Ethiopia consists of 10 administrative regions, of which Amhara, Oromia, SNNP (Southern Nations, Nationalities, and Peoples) and Tigray are the largest. Together, these four regions account for a little over 97% of national production value and cultivated area of grain crops (CSA, 2018). In terms of production, the shares in total grain production value for the 2017/2018 *meher* season[1] were as follows: Oromia (49.4%), Amhara (32.8%), SNNP (9.0%) and Tigray (6.1%). Similar shares hold for the area planted with grain crops: Oromia (45.4%), Amhara (35.3%), SNNP (8.9%) and Tigray (7.4%).

2.2 Agro-ecological zones

Ethiopia is a large country with great diversity in terms of altitudes, topography, soils, natural vegetation, rainfall patterns and climate. A major distinction is to be made between the densely populated **highlands** (> 1,500 m altitude) and the **lowlands** (< 1,500 m altitude). They each make up about half of the total land area of the country, but close to 90% of the population and about 95% of the cultivated area is situated in the highlands. The resulting pressure on land results in difficult access to farmland, small farm sizes and farming of a (semi)subsistence nature. Population density in the lowland areas is much lower, with less than 15% of the population and largely pastoral and agro-pastoral farming systems. There is nevertheless huge potential for irrigation-based agriculture, which has hardly been developed to date.

Traditionally, the highlands are further divided into four agro-ecological zones[2]: Woina Dega, Dega, Wurch and Kur (CSA, EDRI and IFPRI, 2006), as illustrated in Figure 1. Woina Dega and Dega are best suited to rainfed farming. All major rainfed crops can be grown in most parts of this belt, with wheat, teff, and maize being the major ones. The lower part of Woina Dega is also suitable for cash crops such as coffee, tea and enset. Wurch and Kur have altitudes of over 3,200 m, and apart from barley production in the former, these zones are mostly used for grazing animals.

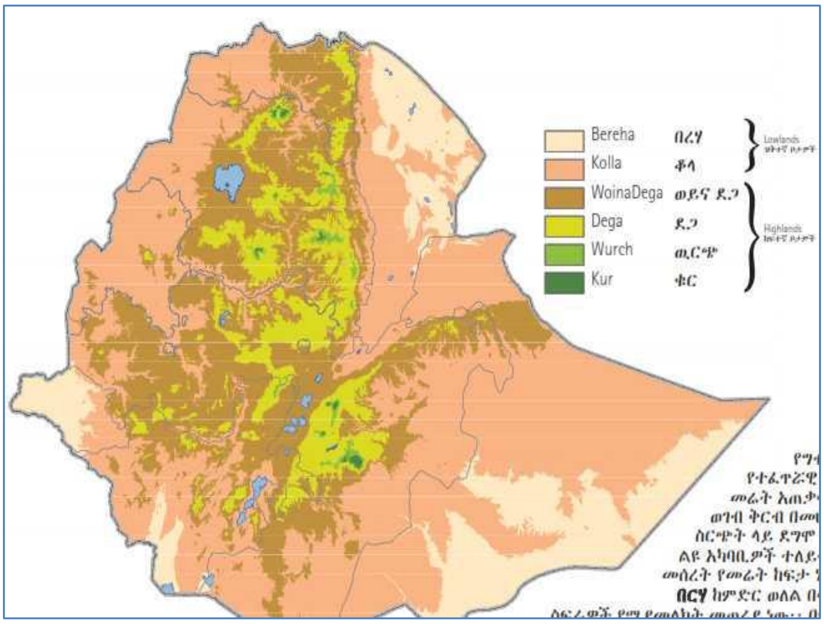
The lowland areas consist of Bereha and Kolla, characterized by high temperatures and limited and variable rainfall. The major livelihood systems in these areas are agro-pastoral. In the Kolla zone, the dominant crop is sorghum. In some areas, maize and teff can be grown. Bereha represents the lowest altitude, with hardly any crop production in the arid east. In the west, some mixed root crops and maize are grown if rainfall permits, but overall rainfed agriculture in this zone is very limited. Some large-scale irrigation projects have been developed, particularly along the Awash river.

The zones of rainfed agriculture in the highlands are largely situated in the four largest administrative regions: Amhara, Oromia, SNNP and Tigray.

[1] *Meher* is the main rainy crop season in Ethiopia, with harvests between the months of September (*Meskerm*) and February (*Yekatit*). By contrast, any crop that is part of the *belg* short rainy season is harvested between the months of March (*Megabit*) and August (*Pagume*). The *meher* crop season produces about 95% of total annual crop production (CSA, 2018a).

[2] Given the high diversity in the country in terms of agro-climatic conditions and ecological systems, a more detailed agro-ecological division of the country has been developed, consisting of 33 zones (Derge and Eshetu, 2011). This is believed to provide a better representation of the country's diverse genetic resources and agricultural production systems.

Figure 1: Map of the six traditional Ethiopian agro-ecological zones



Source: CSA, EDRI and IFPRI (2006)

2.3 Agricultural land and water resources

Ethiopia's total surface area is estimated at 110 million hectares (ha) (WDI, 2018). About 36% is highlands and the remaining 64% lowlands. The great majority of human and livestock population (about 85% and 70%, respectively) are located in the highland areas (Alemu, 2006). As a result, the highlands are densely populated and farm size is declining. Arable land has expanded by more than 50% over the past two decades, but given fast population growth, the arable land availability per person has remained more or less unchanged at around 0.15 ha per person (Table 1). This obviously results in very small farm sizes. On average, households cultivate 11 fields with an average field size of 0.11 ha. Average total land holding is 1.22 ha, of which 0.92 ha is cultivated (CSA and LSMS, 2015a).

Table 1: Evolution of agricultural land in Ethiopia

	1995	2000	2005	2010	2015
Agricultural land (% of land area)	30.5	30.7	33.6	35.7	36.3
Arable land (% of land area)	9.9	10.0	12.8	14.6	15.1
Arable land (ha per person)	0.17	0.15	0.17	0.17	0.15
Agricultural irrigated land (% of total agricultural land)	.	.	0.44	0.51	.

Source: World Development Indicators (2018).

Ethiopia is endowed with abundant water resources. A large number of rivers form a network covering most of the country (Solomon, 2006). However, most are transboundary rivers, which create challenges in terms of the exploitation of water resources. Several studies have emphasized the huge irrigation potential of the country, both through surface and groundwater (Solomon, 2006; Awulachew et al., 2007; Haile, 2015). Nevertheless, irrigated land currently remains very low, at about 0.5% of total agricultural land (Table 1).

2.4 Major crop production

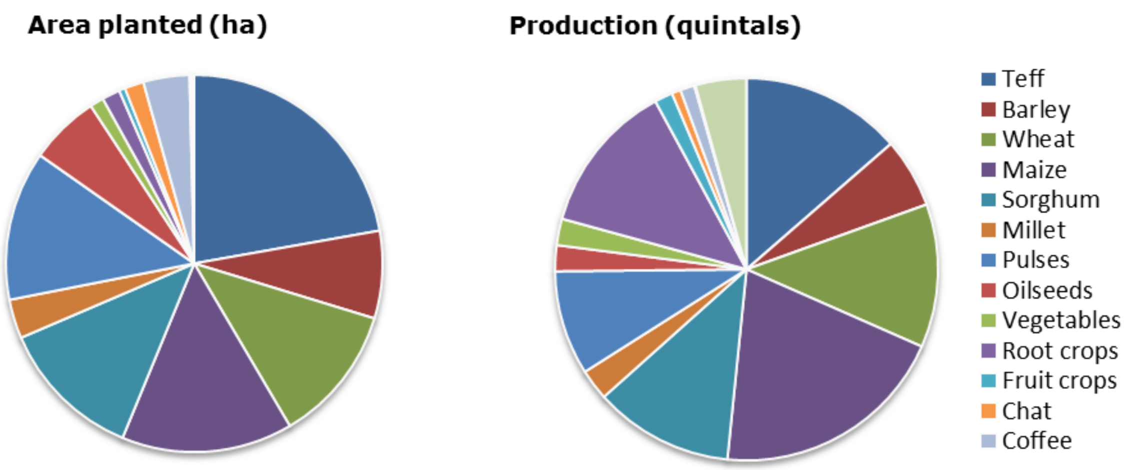
The bulk of Ethiopia's agricultural production consists of grains, with primary grains being maize, teff, sorghum and wheat. Table 2 and Figure 2 represent the main distribution of cultivated land and agricultural production across the main crops for the 2013-2014 *meher* season, according to the Agricultural Sample Survey (AgSS) collected by the Central Statistical Agency (CSA, 2014a). The large majority (90.8%) of cultivated area is planted with field crops (cereals, pulses and oilseeds), most of it cereals. Teff makes up 22.1% of all cultivated land, followed by maize (14.6%), sorghum (12.3%) and wheat (11.8%). In terms of the number of farmers cultivating the crop, maize and teff are the most widely grown grains, but pulses, vegetables and root crops are also widely cultivated. Despite teff's larger share of cultivated land, in terms of production, maize is the most important crop (19.9% of total production) because of its higher yield (32.54 quintals/ha). Teff, wheat and sorghum contribute, respectively, 13.6%, 12.0% and 11.7% of total production. Thus, these four cereals (maize, teff, wheat and sorghum) are crucial crops for Ethiopian agriculture as they account for more than half (57.2%) of the country's total crop production[3].

Table 2: Area, production and number of holders by crop (*meher* season, 2013/14)

Crop	Total area (hectares, ha)	%	Production (quintals, qt)	%	Number of holders
Grain crops	12,407,473	90.80	251,536,624	77.14	14,093,660
Cereals	9,848,746	72.07	215,835,226	66.19	13,419,762
Teff	3,016,522	22.08	44,186,422	13.55	6,613,090
Barley	1,019,478	7.46	19,082,624	5.85	4,461,616
Wheat	1,605,654	11.75	39,251,741	12.04	4,746,231
Maize	1,994,814	14.60	64,915,403	19.91	8,809,221
Sorghum	1,677,486	12.28	38,288,701	11.74	4,788,499
Millet	454,662	3.33	8,489,564	2.60	1,608,823
Pulses	1,742,602	12.75	28,588,806	8.77	8,336,953
Oilseeds	816,125	5.97	7,112,592	2.18	3,687,135
Vegetables	161,488	1.18	7,228,937	2.22	6,168,016
Root crops	209,880	1.54	41,608,725	12.76	6,403,663
Fruit crops	71,507	0.52	4,991,838	1.53	3,612,308
Chat	222,079	1.63	2,450,629	0.75	2,755,204
Coffee	538,467	3.94	3,920,062	1.20	4,546,785
Hops	24,727	0.18	305,876	0.09	2,136,154
Sugar cane	29,104	0.21	14,034,441	4.30	1,151,342

Source: CSA (2014a).

Figure 2: Cultivated land and production by crops in Ethiopia (*meher* season, 2013/14)



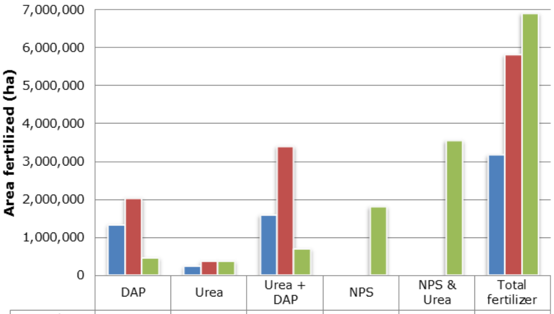
Source: CSA (2014a).

[3] The production distribution of all crops for 2017/2018 *meher* season is similar to that reported for 2013/2014. For example, the corresponding production shares of maize, teff, wheat and sorghum are 21.7%, 13.6%, 13.3% and 12.0%, respectively. Thus, these four major crops made up 60.6% of total crop production in Ethiopia in the latest reported year of 2017/2018 (CSA, 2018b).

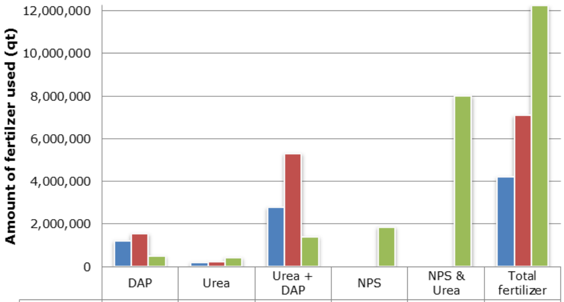
2.5 Input use

Despite fast growth over the past two decades, use of modern inputs remains limited in Ethiopia. The share of cultivated area that is fertilized, either organically or inorganically, increased from 39.9% in 2009/2010 to 52.5% in 2013/2014 and further to 56.8% in 2017/2018 (CSA, 2010, 2014b, 2018c). Of the total fertilized area (7.4 million ha) in 2013/14, about 78% had inorganic fertilizer applied, mostly a combination of DAP and urea. In 2017/18 inorganic fertilizer was applied to about 83% of total fertilized area (8.3 million ha), with the following area distribution of fertilizer applied (see Figure 3): NPS and urea (51.4%), NPS (26.3%), urea and DAP (10.1%), DAP (6.8%), and urea (5.4%).

Figure 3: Fertilizer applied area (ha) and quantity (qt)



	DAP	Urea	Urea + DAP	NPS	NPS & Urea	Total fertilizer
2009/2010	1,336,931	237,396	1,593,079			3,167,406
2013/2014	2,034,280	373,713	3,398,326			5,806,319
2017/2018	466,482	371,034	700,274	1,813,374	3,549,465	6,900,629

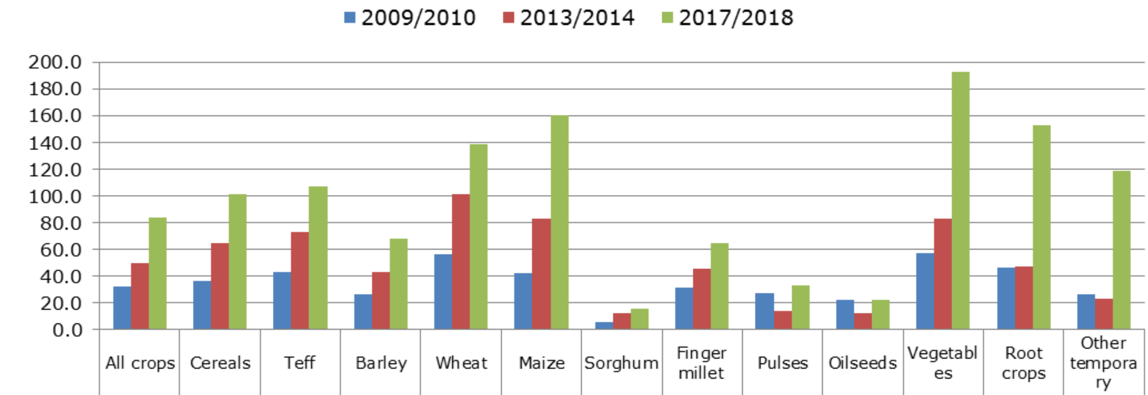


	DAP	Urea	Urea + DAP	NPS	NPS & Urea	Total fertilizer
2009/2010	1,229,530	213,026	2,784,939			4,227,495
2013/2014	1,555,730	226,836	5,322,080			7,104,646
2017/2018	499,653	427,454	1,422,405	1,874,519	8,029,703	12,253,734

Source: CSA (2010, 2014b, 2018c).

The total amount of inorganic fertilizer used increased from 4.2 million quintals (qt) in 2009/10 to 7.1 million qt in 2013/14 and further increased to 12.2 million qt in 2017/18. As shown in Figure 3, NPS fertilizer has recently been gaining prominence in Ethiopian agriculture, both in terms of fertilizer applied area and quantity, in particular replacing DAP. Most of the fertilizer used in 2017/18 was applied to cereal crops (about 10.4 million qt), of which teff accounted for 3.2 million qt, wheat 2.4 million qt and maize 3.4 million qt of fertilizer. The largest area to which fertilizer was applied was that of teff crops (about 2.4 million ha), followed by maize (about 1.7 thousand ha) and wheat (roughly 1.5 million ha) (CSA, 2018c).

Figure 4: Fertilizer intensities (kg used per ha of crop area)



	All crops	Cereals	Teff	Barley	Wheat	Maize	Sorghum	Finger millet	Pulses	Oilseeds	Vegetables	Root crops	Other temporary
2009/2010	32.6	36.2	43.3	26.9	56.7	42.1	5.8	31.4	27.6	22.7	57.6	46.1	26.7
2013/2014	50.2	64.6	72.8	43.6	101.1	83.4	12.1	46.0	14.5	12.5	83.1	47.2	23.7
2017/2018	84.0	101.2	106.9	68.5	139.1	160.2	16.1	64.8	33.0	22.6	192.7	152.7	118.8

Source: CSA (2010, 2014b, 2018c) and authors' calculations.

The fertilizer intensity rates by crop are presented in Figure 4. Average fertilizer use per cultivated area (whether fertilized or not) increased from 32.6 kg/ha in 2009/10 to 84.0 kg/ha in 2017/18. For cereals, average fertilizer intensity increased by 179% over the period considered, from 36.2 kg/ha in 2009/10 to 101.2 kg/ha in 2017/18. Furthermore, the largest increase in average fertilizer rates is observed for vegetables, root crops and other temporary crops, with respective growth rates of 235%, 231% and 345%. Nevertheless, it should be noted that overall a large part of the crop area remains unfertilized: for 60.1%, 47.4% and 43.2% of the cultivated area in the respective years no inorganic fertilizer was applied at all, and fertilizer use remains far below recommended rates (IFPRI, 2010; AGRA, 2014).

In terms of seeds, the use of traditional seed is still predominant, although the quantity of improved seed used has been growing over time. Table 3 shows that the volume of improved seeds used in 2017/18, according to the AgSS data, was estimated at about 593 thousand qt, which represents a 149.3% increase compared to that in 2009/2010. Most of the improved seeds (74% in 2009/10 and 86% in 2017/18) are maize seeds (e.g. 53% in 2017/18) and wheat seeds (e.g. 33% in 2017/18). At the same time, very little improved seed is used for sorghum and millet. The predominance of traditional seed use can be seen in the fact that total improved seed use made up only 3.1% and 6.6% of the total traditional seeds used in 2009/10 and 2017/18, respectively. The only exception is maize, where improved seeds made up 20.2% and 61.7% of total volume of traditional seeds used in 2009/10 and 2017/18, respectively.

Table 3: Traditional and improved seed use (*meher* season, quintals)

Crop type	2009/2010		2017/2018		Percentage change (2017/2018 vs 2009/2010)	
	Indigenous seed (qt)	Improved seed (qt)	Indigenous seed (qt)	Improved seed (qt)		
All	7,692,845	237,751	9,047,656	592,765	17.61	149.32
Cereals	5,814,495	219,987	7,126,358	578,896	22.56	163.15
Teff	1,262,500	19,304	1,453,118	19,854	15.10	2.85
Barley	1,441,630	17,143	1,500,825	45,103	4.11	163.10
Wheat	1,988,935	73,271	2,833,886	195,955	42.48	167.44
Maize	505,333	102,112	511,957	315,689	1.31	209.16
Sorghum	341,893	3,862	465,093	1,319	36.03	-65.85
Finger millet	148,545	1,194	190,744	NA	28.41	
Pulses	1,610,354	14,231	1,685,902	13,121	4.69	-7.80
Oilseeds	267,996	3,533	235,396	NA	-12.16	

Source: CSA (2010, 2018c).

Table 4 gives the details of all input use, in terms of area, for the last reported year of 2017/2018. For all crops, improved seeds were applied to about 10% of all crop area, compared to only 3% in 2009/10 (not reported here). In terms of improved seed applied area, maize is largely outpacing all other crops: about 55% of its cultivated area uses improved seed. With a large gap, maize is followed by wheat, for which improved seed applied area was only about 7% of cultivated area in 2017/18.

In addition, herbicides and phytosanitary products are commonly used to control weeds, fungus, pests and insects, especially for wheat, barley and maize (CSA and LSMS, 2015a). The total pesticide applied area was estimated at around 3.9 million ha in 2017/18, representing 26.5% of all crop area in that year. The corresponding proportion in 2009/10 was roughly 12% (not reported here). Most of the crop area to which pesticide was applied was under teff (1.5 million ha) and wheat (948 thousand ha).

Irrigation is another important agricultural input, particularly needed in the event of water shortage due to poor rain or dry spells. However, as is clear from Table 4, Ethiopia is still very far from the desired outcome of irrigation use as recommended by many agricultural experts. The total irrigated crop area in the country within private peasant holdings was estimated at around 181 thousand ha in 2017/18, which represents only 1.2% of all crop area (a similar percentage to eight years previously, in 2009/10). Most of the area irrigated was under maize (25,281 ha), sorghum (24,914 ha) and teff (10,400 ha).

Table 4: Inputs applied area (*meher* season, 2017/2018)

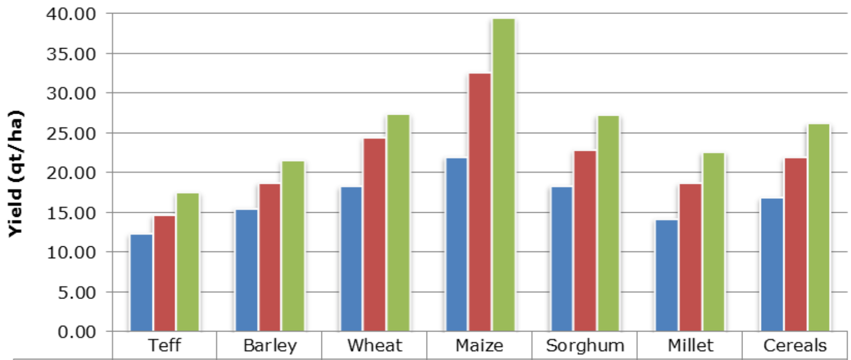
Crop type	All crop area (ha) [1]	Inorganic fertilizers (% of [1])	Indigenous seed (% of [1])	Improved seed (% of [1])	Pesticide (% of [1])	Irrigation (% of [1])	Extension package (% of [1])
All	14,582,195	47.32	90.25	9.75	26.47	1.24	30.89
Cereals	10,232,582	60.90	86.68	13.32	34.24	0.68	39.37
Teff	3,023,284	76.46	98.15	1.85	49.04	0.34	35.81
Barley	951,993	55.39	98.06	1.94	29.13	0.14	25.71
Wheat	1,696,907	84.78	93.44	6.56	55.88	0.29	51.14
Maize	2,128,949	64.11	45.05	54.95	12.70	1.19	61.88
Sorghum	1,896,389	12.69	99.69	0.31	18.24	1.31	16.14
Millet	456,057	65.85	99.77		34.47	0.15	39.65
Pulse	1,598,807	20.48	99.23	0.77	12.77	0.26	14.75
Oilseeds	846,494	8.35	99.54	0.46	4.30	0.08	6.72
Vegetables	208,986	56.83	98.52	1.48	6.58	3.04	31.79
Root crops	233,290	40.16	96.86	3.14	25.76	9.10	25.10
Other temporary	95,015	18.10	96.09				13.45
Fruit crops	104,422		98.37		0.57	13.77	4.49
Chat	262,072		99.95		7.04	13.01	3.59
Coffee	725,961		96.46	3.54	1.08	1.49	3.11
Hops/'Gesho'	31,196		99.21		4.00	14.62	14.09
Enset	197,231		99.57		0.39	0.45	
Sugar cane	29,536		100.00			24.78	
Other permanent	16,602		98.25			6.94	4.87

Source: Authors' calculations based on CSA (2018c).

2.6 Crop yields

There is no doubt that agricultural productivity in Ethiopia has improved impressively, although there is some uncertainty regarding the exact amount of the increase in yields. In fact, some concerns have been raised about the reliability of yield data obtained from the annual AgSS surveys conducted by the CSA in Ethiopia (Dercon and Zeitlin, 2009; Cochrane and Bekele, 2018). Figure 5 below illustrates the yields for the main cereals, based on the official production and area statistics from the CSA. From the figure, one can see a 79.4% increase in maize yield between 2009/10 and 2017/18, while for all cereals an average yield growth of 55.5% over the same period is reported. The corresponding yield growth rates for teff, barley, wheat, sorghum and finger millet are 42.3%, 39.2%, 49.8%, 48.5% and 59.0%, respectively.

Figure 5: Yields (qt/ha) for main cereals in Ethiopia based on AgSS data

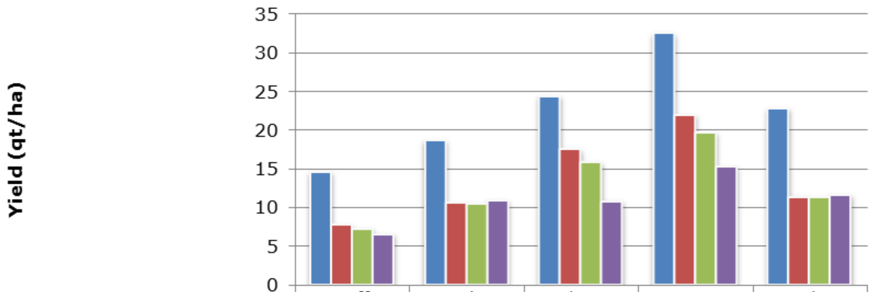


	Teff	Barley	Wheat	Maize	Sorghum	Millet	Cereals
2009/10	12.28	15.50	18.27	21.99	18.36	14.21	16.82
2013/14	14.65	18.72	24.45	32.54	22.83	18.67	21.91
2017/18	17.48	21.57	27.36	39.44	27.26	22.60	26.17

Source: CSA (2010, 2014b, 2018c).

However, as already indicated above, there are some doubts as to whether the reported yield growth is accurate, especially when compared: (i) to the more modest increase in input use (see for example the changes in conventional seed use in Table 3), (ii) to yield levels in surrounding countries, and (iii) to yield growth rates in Asia (Dercon and Hill, 2009). Alemu et al. (2008) also compare yield statistics from various studies and conclude that official yield statistics are high. Figure 6 compares the official statistics derived from the AgSS survey (CSA, 2014a) to the statistics derived from the Ethiopian Socioeconomic Survey (CSA and LSMS, 2015a) for the same year, both before and after winsorizing to control for outliers. Indeed, Figure 6 shows that the AgSS yields for the main cereals are much higher than those based on the ESS survey. The AgSS yields for wheat, teff, maize, sorghum and barley are higher than their ESS equivalents by 125.1%, 121.3%, 112.2%, 95.4% and 70.8%, respectively, which is indeed a significant difference. Compared to the weighted average yields used in the FSSIM-Dev model (Figure 6, final bar), the AgSS yields are again quite high. Recall that the yields used in the FSSIM-Dev model are based on the ESS data but treated and cleaned in a slightly different way, which is explained in section 3 and Appendix A.

Figure 6: Yields (qt/ha) for main cereals in Ethiopia: AgSS and ESS data comparison



	Teff	Barley	Wheat	Maize	Sorghum
CSA AgSS 2013/14	14.65	18.72	24.45	32.54	22.83
LSMS 2013/14 (untreated)	7.76	10.59	17.54	22.02	11.43
LSMS 2013/14 (winsorized)	7.27	10.45	15.84	19.73	11.30
FSSIM-Dev (2013/14)	6.62	10.96	10.86	15.33	11.68

Source: CSA (2014a), CSA and LSMS (2015a, Table 4.6) and authors' calculations.

There are several explanations for the difference between these estimates. The AgSS yield data are calculated based on estimations of area planted and production, which in turn are based on GPS-measured planting area for all fields, and crop-cut yields on randomly selected fields. Dercon and Hill (2009) call for a careful review of how these data are collected and collated. The ESS survey relies on a much smaller sample, but is designed to be representative for the four main agricultural regions. ESS yield data are derived from farmers' reported harvest and GPS or compass-rope measured area. Outlier correction by the World Bank LSMS team consisted of winsorizing at 2%.

2.7 Policy context: modern input use and GTP II targets

Since the 1990s, agriculture has been central to Ethiopia's development strategy. In 1993, the Ethiopian government adopted a development strategy broadly known as Agricultural Development Led Industrialization (ADLI). This long-term strategy is based on the view that promoting agricultural growth is a first step towards generating overall economic progress, through structural transformation. This is also reflected in the budget. Between 2002/03 and 2011/12, on average 15% of the government's development budget was allocated to agriculture (Berhanu and Poulton, 2014), well above the 10% that African governments committed to allocate to agriculture under the Maputo Declaration in 2003, and which many other African countries have failed to achieve. Over the past decades, several major initiatives have been developed to realize the ADLI strategy, including the Poverty Reduction Strategy Paper (PRSP, 2002-2009) and the Growth and Transformation Plans: GTP I (2010-2015) and GTP II (2015-2020).

Ethiopia's major rural development strategies typically have a double and geographically differentiated focus. On the one hand, rural development policy focuses on poverty reduction and food security. Since 2005, the Productive Safety Net Programme (PSNP) which ensures transfers to the poorest households, has been its most important pillar. On the other hand, the government has increasingly focused on the commercialization and intensification of agriculture, including the promotion of high-value crops, and specific interventions for selected high-potential agricultural areas. The Agricultural Growth Program is a comprehensive agricultural development programme, focused at high potential areas and aiming to increase agricultural productivity and commercialization of small- and medium-sized farms. This will be the focus of our policy scenarios assessment within the FSSIM-Dev model and thus will be discussed in detail in section 6.

Via these programmes, the Ethiopian government has mostly relied on measures that aim to improve the functioning of input, output and credit markets, and to increase farmers' knowledge of input use and best agricultural practices. There is no nationwide subsidy programme for inputs or outputs, although the fertilizer market is controlled by the state which is argued to result in an implicit subsidy (Rachid et al., 2013). Input voucher programmes and micro-finance institutions are developed to promote modern input use. Through support for cooperatives, the government aims to improve the link between small-scale farmers and the commercial sector. In addition, the government has massively invested in the agricultural extension system (e.g. Participatory Demonstration and Training Extension System, PADETES) to introduce and encourage the adoption of new agricultural technologies.

Improved seeds and chemical fertilizer

The promotion of modern inputs is central to Ethiopia's agricultural policy, which has emphasized the development of improved cultivars (short for 'cultivated varieties'). The government of Ethiopia has dedicated significant effort and budget to the promotion of packages of improved seeds and chemical fertilizer and has invested significantly in improving and expanding agricultural extension services. The literature (e.g. Feder, 1982; Abay et al., 2018; Bachewe et al., 2018) identifies at least three reasons for considering these two inputs jointly. Firstly, simultaneous adoption can lead to higher average yield increases than when adopted separately, due to complementarity effects. Secondly, the combined use of two or more inputs can at times be risk-reducing, in the sense that the synergistic use leads to better outcomes, as in the case of a particular seed becoming more drought- or damage-resistant if used with specialized nutrients. Thirdly, in the context of Ethiopia, agricultural input supply strategies over the last decade encouraged farmers to adopt chemical fertilizers and improved seeds as a package, at times bundled with input credit, making adoption of these two inputs an inherently simultaneous decision or a choice between possible sets of technology bundles.

The structure of the fertilizer market has changed considerably over the past decades (Rashid et al., 2013). The centrally planned fertilizer policy of the communist period was gradually liberalized from 1992. The promotion of the credit-fertilizer package was accompanied by a further liberalization of the fertilizer market, including the removal of fertilizer subsidy and administrative fertilizer price, which caused private actors to enter the market. Over this entire period, the governments' input marketing agency AISC/AISE (Agricultural Inputs Supply Corporation, later Agricultural Inputs Supply Enterprise) has played a central role in fertilizer marketing and distribution. When the New Marketing System was introduced in 1992, there was a slow entry of private companies, as well as holding companies managed by the regional governments. Private sector participation, however, was short-lived and by 2002 no more private companies were active in the fertilizer market. Since the 2000s, the regional governments have invested in the involvement of cooperatives in the input marketing system, and by 2007/08 almost 75% of total fertilizer use passed through the cooperatives, who received subsidized credits to import and distribute fertilizer (Rashid et al., 2013). From 2009 onwards, the government decided to coordinate all fertilizer inputs through AISE, leading to the withdrawal of the regional holding companies. Since then, all fertilizer in Ethiopia is imported through AISE, based on the idea that by aggregating the demand, AISE has more bargaining power to negotiate lower prices and to reduce transaction costs. Thus, since 2008 the government has a monopoly over fertilizer imports, with exclusive marketing through farmers' cooperatives.

Fertilizer demand for the next year is assessed based on estimates by the extension agents and cooperatives in each *woreda*, which are subsequently aggregated at zone level. Based on these zone-level estimates and taking into account regional production targets, each regional Bureau of Agriculture and Rural Development (BoARD) sends a demand estimate to the Ministry (MoARD), which aggregates them into a national estimate and launches a tender for fertilizer imports. AISE is then responsible for executing these imports. Once fertilizer arrives at Djibouti port, AISE informs the regional cooperatives, which are in charge of organizing transport and distribution to the primary cooperatives.

The average price of fertilizer is set by AISE at the central warehouse level, and the BoARD adds margins for cooperatives, transport and storage costs, bank interest rates and other administrative costs, to come up with a regional price. The regional BoARDs also facilitate input credit guarantees for the Cooperative Unions. The primary unions then receive fertilizer on credit from the unions and sell mostly in cash to smallholder farmers. In some remote and food insecure areas, farmers can receive fertilizer with subsidized credit, paying 50%

before harvest and the remainder after harvest; several micro-finance and saving or credit unions exist to provide farmers with credit for fertilizer.

The use of chemical fertilizer has been increasing rapidly since 1995, when the country adopted the new PADETES extension. Fertilizer use grew by 70%, from 190,000 metric tonnes in 1994 to 323,000 tonnes in 2003/04. By 2015/16, fertilizer use had increased to 1.1 million tonnes (CSA, 2015/16), an increase of over three times (340%) in just over 12 years. Total fertilizer imports in Ethiopia were below 100,000 tonnes up to the mid-1990s, but increased to 440,000 tonnes in 2008 and 890,000 tonnes in 2012. These numbers illustrate the mismatch, with governments' targets being well above actual fertilizer demand, leading to large amounts of imported fertilizer ending up in carry-over stock (Rashid et al., 2013).

Under the centrally planned system, the AISC controlled system involved large direct subsidies and high administrative costs. Since then, Ethiopia has had no official fertilizer subsidy programme, although several government agencies involved do absorb a substantial amount of the costs related to fertilizer marketing and distribution. Rashid et al. (2013) estimated the composition of costs and margins in the fertilizer supply chain, and concluded that even though there is no official subsidy programme, fertilizer prices are considerably lower than in neighbouring countries, due to implicit costs carried by the different agencies involved (lower bank interest on fertilizer, no spoilage allowance and storage costs, very low margins for primary cooperatives, costs associated with the carry-over stocks). Rashid et al. (2013) provide a detailed analysis of the cost build-up of fertilizer in Ethiopia, by region. They calculate that between 64% and 80% of the farm gate price of fertilizer relates to transport costs. All in all, it is argued that many government agencies involved in the administration, marketing and distribution of fertilizer do absorb many of the distribution costs and operate subsidized interest rates, resulting in a hidden fertilizer subsidy.

Fertilizer is distributed on credit to the cooperatives, who sell it mostly in cash to the farmers. Although there is no official universal fertilizer subsidy programme, in some remote areas farmers can receive fertilizer with subsidized credit, and input voucher programmes have been set up to promote modern input use (often a combination of improved seeds and fertilizer) in specific areas of the country. After pilot tests of the input voucher credit programme, this programme is being scaled up and implemented through micro-finance institutions and rural saving and credit cooperatives (ATA, 2017).

Extension policy

Throughout the past rural development programmes, Ethiopia has put major emphasis on the role of information and training for farmers. A major initiative in the first poverty strategy was the development of the widespread extension programme PADETES, including advanced training programmes for extension agents. Through this system, the government also delivered off-the-shelf packages of fertilizer, improved seed and credit, as well as information on input use and better agricultural practices, to the vast majority of smallholders in rural areas. Ethiopia has the highest extension-to-farmer rate in Africa (see e.g. Ragasa et. 2013; ARGA, 2018).

The total number of farm holders participating in the various agricultural extension services increased from about 3.1 million in 2009/10 to 6.6 million in 2013/14 and further increased to 8.1 million by 2017/18. As shown in Table 4, around 31% of all cultivated land was covered by the extension package programme in 2017/18, compared with 12% back in 2009/10. In 2017/18, most of the area under the extension programme was reported to be under maize (1.3 million ha), teff (1.1 million ha) and wheat (867,000 ha). In general, the area under the extension programme for cereal crops was 1.4 million ha in 2009/10, 3.5 million ha in 2009/10 and 4.0 million ha in 2017/18, while the numbers of cereal growers that participated in extension services were reported to be 2.9 million, 6.2 million and 7.6 million, respectively.

Selected GTP II targets

Given the importance of agriculture to the Ethiopian economy, the Growth and Transformation Plan II (GTP II, 2015/16-2019/20) pays particular attention to agriculture and rural transformation of the country, in order to achieve its final aim of becoming a lower middle-income country by 2025. The GTP II targets relevant to our purposes and related to our study in this report include targets for crop production and productivity, agricultural input supply and utilization, and agricultural extension services. Some selected targets from this list are presented in Table 5.

The targeted growth rate (relative to the base year of 2014/15) for the productivity of major food crops is set at about 47% over the entire period covered by GTP II, equivalent to roughly 8% compound annual productivity growth over the 5-year period. This marked increase in crop productivity is planned to be achieved through three complementary tracks: (1) raising the productivity level of most farmers to yield levels attained by model farmers; (2) raising the productivity and production of model farmers to levels attained by agricultural research centres, by building and improving their capacity; and (3) providing support and capacity building to agricultural research centres to deliver new agricultural technologies (National Planning Commission, 2016, p. 121).

Table 5: Selected GTP II targets

	Base year 2014/2015	Plan targets 2019/2020	Projected growth (%)
	Increased productivity in major food crops		
Average productivity of non-stalk cereals (qt/ha)	21.05	30.92	46.9%
Average productivity of stalk cereals (qt/ha)	28.99	42.64	47.1%
Maize (qt/ha)	34.29	50.38	46.9%
Sorghum (qt/ha)	23.69	34.81	46.9%
Average productivity of pulses (qt/ha)	17.2	23.0	33.4%
Beans (qt/ha)	18.93	27.82	47.0%
Peas (qt/ha)	14.85	21.83	47.0%
Lentils (qt/ha)	13.89	20.40	46.9%
Average productivity of oilseeds (qt/ha)	9.0	12.7	41.1%
	Increased agricultural input utilization		
Quantity of improved seeds supplied (qt)	1,873,778	3,559,924	90.0%
Quantity of chemical fertilizers (tonnes)	1,223,309	2,062,106	68.6%
	Improved agriculture extension services		
Total number of farmers receiving extension service ('000)	13,090	16,776	28.2%
Male-headed farming households receiving extension service ('000)	7,854	9,674	23.2%
Female-headed farming households receiving extension service ('000)	3,927	5,325	35.6%
Total number of trained extension agents	14,100	24,325	72.5%
Number of new crop technologies provided by the research	64	86	34.4%

Source: National Planning Commission (2016), Volumes I and II.

The final target for supply of improved seeds is set at 3.6 million qt, a 90% increase compared with the base year 2014/15. Meanwhile, the supply of chemical fertilizers is planned to reach 2.1 million tonnes by 2019/20, a 69% increase compared to the base year. The implied average (compound) annual growth rates, over the 5-year period of GTP II, are thus equivalent to 13.7% and 11.0% for the supply of improved seeds and fertilizers, respectively. In order to reach these targets, it was envisaged that, for example, the voucher credit system pilot tested in 81 *woredas* would be scaled up to all *woredas* and regions, so that farmers would not be constrained because of limited access to credit. At the same time, rural credit and saving institutions, regional agricultural bureaus and financial institutions would act in a more coordinated manner. In addition, it was planned that the direct distribution system, then still under a pilot scheme, would be expanded to all regions and areas of the country (National Planning Commission, 2016).

Finally, it is believed that the expansion of agricultural extension services will significantly contribute to improving crop productivity. The plan is to increase the number of farmers who benefit from extension services from 13.1 million in 2014/15 to 16.8 million by 2019/20 (Table 5). In particular, female participation in extension programmes is strongly encouraged, with a larger increase foreseen in female-headed vs male-headed farming households receiving these services (36% vs 23%). The number of development agents (experts) is projected to increase by about 73% during the GTP II period, from 14,100 in 2014/15 to 24,325 in 2019/20. In general, the agricultural extension service delivery system was planned to enhance full and effective implementation of the projected scaling up strategy.

3 The FSSIM-Dev model

3.1 General description of the model

In this study, we use the farm household model FSSIM-Dev (Louhichi and Gomez y Paloma, 2014) to *ex ante* assess policy impacts on smallholder farmer livelihoods in Ethiopia. FSSIM-Dev is a micro-simulation tool that is well adapted to evaluate policy impacts on food security and rural poverty alleviation in the specific context of low-income developing economies. It aims to inform policymakers on how changes in prices, technology, food and agricultural policies could affect the viability and food security of heterogeneous sets of farm households that characterize the agricultural sector, which types of farm households will be the most affected, where these most-affected farms are located, etc.

FSSIM-Dev is designed to be applied to family or peasant agriculture, where farm household production, consumption and labour allocation decisions are non-separable due to market imperfections. Peasants are farm households, with access to an (often small) piece of land and utilizing mainly household labour in farm production. They are characterized by partial engagement in markets, which are often imperfect or incomplete due to transaction costs (Ellis, 1992). Peasant farms operate as both production and consumption units: a proportion of produce is sold to meet their cash requirements and financial obligations, and a part is used for self-consumption. If self-produced food is not enough for the family's subsistence, the peasant must turn to the market to fill the gap.

The farm household's production decisions often depend on their consumption requirements, resource endowment, agro-ecological conditions and socioeconomic contexts, while their consumption decisions are mainly driven by the income generated from farming activities, the household members and their preferences, and off-farm incomes. Both production and consumption decisions are affected by prices, which are in turn affected by international markets and trade, infrastructure and market efficiency. This dual character of farm households as producers and consumers has the important implication that increases in food commodity prices create both positive income and negative consumption effects. Therefore, FSSIM-Dev aims to capture this dual nature of peasant/small farm households, as well as the other key features of developing countries' agriculture such as: (i) heterogeneity of farm households with respect to both their consumption baskets and resource endowments; (ii) inter-linkage between transaction costs and market participation decisions; and (iii) seasonality of farming activities and resource use.

FSSIM-Dev is a comparative static and Positive Mathematical Programming (PMP) model (i.e. non-linear programming model). Static means that the model optimizes an objective function for one period (e.g. one average base year) over which decisions are taken; thus it does not explicitly account for time. Positive means that the model aims to reproduce the real conditions under which the farmer operates (i.e. system) as accurately as possible and to simulate 'what is likely' to happen to this situation when changing external conditions, i.e. exogenous shocks, occur (Howitt, 1995).

In FSSIM-Dev, farm households are assumed to be: (i) rational decision-makers under the given conditions; (ii) full (i.e. farm household) income maximizers; and (iii) price takers (i.e. they have no control over input and output market prices).

FSSIM-Dev was designed to be sufficiently generic and with transparent syntaxes, in order to be applied to many different farming systems across Africa and elsewhere in developing economies. It has a modular setup to make it re-usable, adaptable and easily extendable to achieve different modelling goals.

The principal outputs generated by FSSIM-Dev for a specific policy scenario are indicators of crop mix and agricultural production, resources and input uses, food and non-food consumption, farm household income, poverty gap and eventually government expenditure. These indicators are calculated at farm household level but can easily be aggregated at any scale relevant for policymakers. Moreover, as long as a representative survey is used, the results aggregated for the whole sample (with specific sample weight for each household) can be seen as the impact at the national level. Also, the results can be presented according to the characteristics of the farm households, such as the amount of land cultivated by the household, the specialization of the farm, or any other criteria that may be relevant to studying the redistributive effects of the policy. However, these results should not be considered as projections or forecasts, but as indications of trends triggered by exogenous shocks.

The model's capabilities are illustrated by an analysis of the effects of rice seed policy on the livelihood of farm households in Sierra Leone (Louhichi and Gomez y Paloma, 2014) as well as an *ex post* evaluation of an animal traction programme in Ivory Coast (Tillie et al., 2018).

3.2 Mathematical structure and formulation

FSSIM-Dev is a constrained optimization model which relies on both the general household's utility framework and the farm's technical production constraints, in a non-separable regime. Consequently, for each single farm household, it maximizes the income of the household subject to resource endowments (land and labour) and other constraints covered below.

Farm household income (*R*) is defined as the income earned from all economic activities of family members of the same household. It is composed of three components: agricultural income, income from marketed factors of production (non-farm wages, rent of land and equipment) and off-agricultural incomes. Agricultural (farm) income is defined as the income earned by households from selling or consuming their own agricultural products. Off-farm incomes are defined exogenously and can originate from different sources such as non-farm wages, self-employed activities (petty trading, craftsmanship, etc.), pensions, transfers (including remittances) and donations.

Agricultural (farm) income is computed as the sum of agricultural gross margin minus a non-linear (quadratic) activity-specific function. Gross margin is the total revenue from agricultural activities, including sales and self-consumption, minus the accounting variable costs of production activities. The accounting costs include costs of seeds, fertilizers, crop protection, and other specific costs. The quadratic activity-specific function is a behavioural function introduced to calibrate the farm model to an observed base year situation, as is usually done in Positive Mathematical Programming (PMP) models. The PMP methodology (Howitt, 1995), recently refined by Mérel and Bucaram (2010), intends to reproduce households' production and consumption decisions in a precise way, allowing capture of the effects of factors that are not explicitly included in the model, such as price expectations, risk-adverse behaviour, capital constraints and other unobserved costs (Heckelei, 2002).

A crop-specific quadratic yield response function to nitrogen fertilizer, considered as the most important nutrient in sub-Saharan Africa, was also econometrically estimated and then calibrated to the observed level and embedded in the model, under the assumption that yields are independent of acreage planted. This yield response function allows a better representation of the behaviour of the farm household, which could easily adapt its nitrogen fertilizer use to the physical (climatic and soil) and economic (market and policy) context. It also enables recommendations on fertilizer rates to be made under different policy options.

Agricultural commodity prices (i.e. market prices) are exogenously fixed for households participating in markets. We assume that those farm households are price takers on commodity markets. However, the price at which the household values a commodity will be generated by the model, depending on household trading status (net buyer, net seller or self-sufficient), which in turn is related to transaction costs.

In addition to resource endowment and consumption constraints, FSSIM-Dev involves three blocks of equations for modelling market participation decisions: the first block for upper and lower bounds commodity prices; the second, known as complementary slackness conditions, to guarantee that a farm household uses its own internal shadow price if and only if it does not participate in the market for goods; and the third one to ensure that, for each commodity, a farm household can be either a buyer or a seller but not both (households can also be self-sufficient, i.e. neither buying nor selling goods). It also includes a market clearing condition at household level to ensure commodity balance: the sum of production and market demand for each commodity must be equal to consumption plus market sales.

The general mathematical formulation of the model for each farm household h is as follows:

$$Max\ R_h = \sum_i \left(s_{h,i} + cs_{h,i}\right) P_{h,i} + \sum_i sb_{h,i} x_{h,i} - \sum_{i,k} a_{h,i,k} x_{h,i} - \sum_i \left(d_{h,i} + 0.5 Q_{h,i,i'} x_{h,i}\right) x_{h,i} + exinc_h \quad (1)$$

subject to:

$$\sum_{tf} A_{h,i,tf} x_{h,i} \leq B_{h,tf} \qquad [\rho_{h,tf}] \tag{2}$$

$$c_{h,j}P_{h,j} = \delta_{h,j}\left(R_h - \sum_{j'} \upsilon_{h,j'}P_{h,j'}\right) + \upsilon_{h,j}P_{h,j} \tag{3}$$

$$s_{h,j}b_{h,j} = 0 \tag{4}$$

$$p_j^m t_{h,j}^s \leq p_{h,j} \leq p_j^m t_{h,j}^b \tag{5}$$

$$s_{h,j}(p_{h,j} - p_j^m t_{h,j}^s) = 0 \tag{6.1}$$

$$b_{h,j}(p_{h,j} - p_j^m t_{h,j}^b) = 0 \tag{6.2}$$

$$q_{h,j} = s_{h,j} + cs_{h,j}\ ;\ c_{h,j} = cs_{h,j} + b_{h,j};\ q_{h,j} + b_{h,j} = s_{h,j} + c_{h,j} \tag{7}$$

$$y_{h,j} = \alpha N_{h,j} + \beta N_{h,j}^2 + \mu_{h,j} \tag{8}$$

where indices *i = 1 2,…,I* and *j = 1 2,…,J* denote agricultural activities and products[4] respectively, and *k = 1 2,…,K* are intermediate inputs (i.e. fertilizer, seeds, crop protection, etc.). R_h is the total income of the household h, **s** is the *(n×1)* vector of sold quantities of goods, **cs** is the *(n×1)* vector of self-consumed quantities of goods, **p** is the *(n×1)* vector of expected prices of the goods, **sb** is the *(n×1)* vector of production subsidies, **x** is the *(n×1)* vector of the non-negative levels of the agricultural activities, **a** is the *(n×k)* matrix of accounting variable costs, **d** is the *(n×1)* vector of the linear part of the activities' behavioural activity function, and **Q** is the *(n×n)* symmetric, (semi)positive matrix of the same function; *exinc* is the off-farm household's income;

y is the *(n×1)* vector of crop yield (kg per ha^{-1}), **N** is the *(n×1)* vector of the applied nitrogen fertilizer (kg per ha^{-1}), and $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$ and $\boldsymbol{\mu}$ are, respectively, the linear terms, the quadratic terms and the intercepts of the crop yield response functions (the latter details are given in section 4.4);

A is the *(n×m)* vector of resource requirements (e.g. land, labour), **B** is the *(m×1)* vector of initial resource endowments and ρ is the *(m×1)* vector of their corresponding shadow prices. **c** is the *(n×1)* vector of consumed quantity of goods, $\boldsymbol{\upsilon}$ is the uncompressible consumption (interpreted as minimum subsistence or "committed" quantities below which consumption cannot fall), and $\boldsymbol{\delta}$ is the marginal budget share $\left(\frac{\partial(c_{h,j}P_{h,j})}{\partial R_h}\right)$. $\boldsymbol{\upsilon}$ and $\boldsymbol{\delta}$ are the unknown parameters to be estimated. $\mathbf{P^m}$ is the *(n×1)* vector of the market price of goods while $\mathbf{t^s}$ and $\mathbf{t^b}$ are *(n×1)* vectors of the transaction costs related to the sales and the purchase respectively, of goods or tradable factors. Eventually, **q** is the *(n×1)* vector of production level;

Q and **d** are estimated using a variant of the Positive Mathematical Programming approach (Louhichi et al., 2018). $\boldsymbol{\upsilon}$ and $\boldsymbol{\delta}$ are estimated simultaneously in each region using the Highest Posterior Density (HPD) estimator and prior information on income elasticities and Frisch parameters.

Equation (1) represents the model's objective function, while equations (2) to (7) are the set of constraints faced by the farm households. Equation (2) is the resource endowment constraint; equation (3) is the household consumption constraints represented through the Linear Expenditure System (LES); equation (4) specifies that for a given product, the household can be either seller or buyer but not both; equation (5) is the upper and lower bounds of the household commodity prices; equations (6.1) and (6.2) represent the complementary slackness conditions; equation (7) is the market clearing condition at the household level, assuming that for each product, the sum of production and purchase equals the consumption plus sales of this product; and equation (8) is the crop yield response function to mineral fertilizer.

[4] To simplify mathematical notations, we assume one product per activity so that indices for activity and product are identical.

The model calibration was performed using an improved approach based on the Highest HPD estimator, with prior information on supply and income elasticities (Louhichi et al., 2018).

The calibration of the supply side of the FSSIM-Dev model aims to replicate the two key observable production decision variables: 'nitrogen fertilizer applied to crop activities at plot level (i.e. by unit of area)' and 'land allocated to production activities at farm level' by taking into account the underlying profit optimization problem. This is performed in two successive steps: first we calibrate the nitrogen fertilizer use, and then the land allocation. Prior information on supply elasticities and on land rental prices is used for the calibration of land allocation. The aim is that the model exactly replicates the observed land allocation crops, as well as the exogenous set of supply elasticities. The calibration to the exogenous supply elasticities is performed in a non-myopic way, i.e. we take into account the effects of changing dual values on the simulation response (Heckelei 2002; Mérel and Bucaram 2010). The supply elasticities considered in the model are summarized in Table A.3 in appendix. The parameters of the behavioural function are estimated only for observed activities in each farm household, meaning that the well-known self-selection problem is not explicitly handled in this estimation. To cope with this problem, we adopted the following ad hoc modelling decisions in the simulation phase: (i) in each region, the gross margin of the non-observed activities is equal to the farm-type average gross margin; (ii) the activity's quadratic function parameter is equal to the activity's average quadratic function parameter within the farm type; and (iii) the linear term's quadratic function is derived from the difference between the gross margin and the dual values of constraints.

The aim of the calibration consumption module is to ensure that the consumption decisions of the farm households during the base year period are exactly reproduced by the optimal solution of the programming model.

More details on the model specification and its equations are supplied in Louhichi et al. (2019) and Louhichi and Gomez y Paloma (2014).

In the following section, we describe the database used to parametrize the model for the Ethiopian case study. We also present the descriptive statistics for the sampled farm households, as well as the results of the farm typology aiming to group farmers into homogeneous groups. Developed on the basis of farms' crop specialization and economic size, this farm typology allows us to present the model results not only at individual and aggregated (regional and national) levels, but also by farm group (specialization and size).

4 FSSIM-Dev application to the Ethiopian case study

Like any individual farm model, FSSIM-Dev is very demanding in terms of data. It requires a significant volume of detailed individual data on households and their farming activities: land allocation, production and crop yields, consumption and its sources (e.g. purchased consumption, own-produced consumption, other sources such as gifts), amount and price of inputs, labour use, sale prices, purchase prices, household income by type, etc. This section provides a description of the data used to parametrize FSSIM-Dev for the Ethiopian case study, as well as the results of the farm typology aiming to group farmers into homogeneous groups.

For the present study, the FSSIM-Dev model has been implemented for the *meher* season 2013/14, corresponding to the period covered by the Ethiopia Socioeconomic Survey. Each farm household included in the Living Standards Measurement Study (LSMS) survey has been modelled individually in order to capture the diversity of Ethiopian production systems.

4.1 Data: the ESS/LSMS-ISA survey

The research described in this report is based on exploitation of the dataset of farm households resulting from the 2013/14 Ethiopia Socioeconomic Survey (ESS, wave two). This very comprehensive survey is conducted by the Central Statistics Agency of Ethiopia (CSA) in collaboration with the World Bank Living Standards Measurement Study (LSMS) team as part of the Integrated Surveys on Agriculture (ISA) programme. Thus, the ESS 2013/14 survey is also referred to as the LSMS-ISA 2013/14 survey. ESS is a nationally representative survey of 5,262 households living in rural and urban areas. It is integrated with the Annual Agricultural Sample Survey (AgSS), and the rural households included in the ESS are a sub-sample of the AgSS sample households.

Note that we opted to use the 2013/14 survey because the more recent 2015/16 survey is characterized by non-typical weather conditions in several zones of the country. Since calibrating the model on a non-typical base year is not desirable, we opted to use the previous survey round instead. The 2013/14 ESS survey covers 5,262 households, 3,323 of which are rural households. The urban part is not used in our model. The ESS sample is a two-stage probability sample. The primary sampling units are the enumeration areas (EAs). For the rural part of the sample, EAs are selected using simple random sampling based on the sample of AgSS enumeration areas, which in turn were selected based on probability proportional to size of population (PPS). The sample covers 290 rural EAs. The second stage of sampling was the selection of households to be interviewed in each EA. For each rural EA, 12 agricultural households were randomly selected from the 30 AgSS households in the sample (which represent households involved in farming or livestock activities). In addition, two non-agricultural households were randomly selected from all non-agricultural households in the selected rural EA. Where there were only one or no such households, more agricultural households were interviewed instead, so that the total number of households per EA remains the same. Three different questionnaires were used, at different levels of data collection: community level, household level, and specific to agricultural activities.

The Ethiopian ESS/LSMS survey featured many different modules, which could be roughly gathered around three topics: (1) household characteristics, consumption and livelihood activities, (2) agricultural activities, and (3) livestock activities. The survey was implemented in three visits. For rural households, the first visit took place between September and October 2013 and concerned the post-planting agriculture questionnaire. The second visit took place between November and December 2013 when the livestock questionnaire was administered. The third visit concerned the household, community and post-harvest agriculture questionnaire and took place from February to April 2014. While the full survey details can be found in CSA and LSMS (2015b), some features of the 2013/14 ESS survey, according to the above-mentioned broad topics it covers, are as follows:

(1) Data on household characteristics, livelihood activities and food and non-food expenses were collected. A 7-day recall methodology was used to collect data on food consumption. All non-farm activities, as well as any other source of income, are reported, for any member of the household.

(2) Data on agricultural activities include a comprehensive description of all fields of the farm, land tenure, type of soil, available infrastructure and agricultural practices. Production costs (labour, input) are collected at plot level. The quantity of family labour, labour exchange and hired labour used for each crop and for different farming operations is also available. Crop output is collected for each plot and each crop on the plot. Plot size was measured by GPS or by the rope-compass method, at least in most cases.

(3) Data on livestock activities include a comprehensive description of all type of herds of animals owned by the farmers, output (sales) and production costs.

Before using the ESS/LSMS-ISA survey data, several steps were performed to screen the data and to convert them to a format that is compatible with the FSSIM-Dev modelling framework. Variables such as quantity of labour and input used, consumption and prices were treated for outliers and missing values, using Tukey's method based on Interquartile Range or winsorizing. After cleaning and dropping out the urban households, and the rural households having no commitment in any agricultural crop activities, the total sample used for the FSSIM-Dev model consists of 2,886 farm households. Table A.1 in appendix provides a list showing the main variables used within the FSSIM-Dev model, how they are derived from the LSMS-ISA data, and the cleaning process that has been applied.

4.2 Description of the FSSIM-Dev sample

Some key sample characteristics are presented in Table 6, including for the main agricultural regions of Ethiopia. The average farm size in our sample is 1.22 ha; however, there is considerable variability across households and regions. In particular, farm size is especially heterogenous in Tigray and least heterogenous in Amhara: the coefficient of variation (i.e. the ratio of standard deviation to the mean) is 3.17 for Tigray but only 0.80 for Amhara, while for the entire country this variability indicator is 1.89. About 60% of households in our sample have a farm size of strictly less than 1 ha.

It also follows from Table 6 that rural farm households cultivate, on average, 10.3 fields with an average field size of 0.12 ha. The highest number of fields, 12.8 fields on average, is cultivated by farmers in SNNP, but their average field size is very low - 0.07 ha. On the other hand, farmers in Tigray cultivate only 6.9 fields on average, but their average field size of 0.24 ha is the largest in the country. All these sample characteristics discussed are consistent with the general view that average farm size in Ethiopia is very low, while the growing rural population has led to a further shrinking of land size and smaller plots. Fallow land made up 10.2% of the total crop area in the sample (3,539.2 ha), but at the regional level the size of fallow area ranged from 3.6% in Tigray to 17.0% in SNNP.

Based on the ESS survey report (CSA and LSMS, 2015a, Table 4.2), about 94% of the farm households own the land they cultivate[5]. A considerable proportion of households was also engaged in some form of land exchange. 12.0% of households rent out some land, 7.2% uses some borrowed land (mainly from others for free use), 24.9% rent in land, and 5.9% use land under a different land arrangement. Yet the average size of cultivated land rented in or out (respectively, 0.15 ha and 0.05 ha) is relatively small compared to size of cultivated owned land (1.01 ha). For the moment, the FSSIM-Dev model does not distinguish between owned or rented land, and considers there to be no land market.

[5] According to the Constitution of Ethiopia, "The right to ownership of rural and urban land, as well as of all natural resources, is exclusively vested in the State and in the peoples of Ethiopia. Land is a common property of the Nations, Nationalities and Peoples of Ethiopia and shall not be subject to sale or to other means of exchange" (Article 40). Thus, ownership in the above cited ESS survey report should be meant to refer to the *right of using a land*, for which farmers are issued certificates.

Table 6: Some sample characteristics

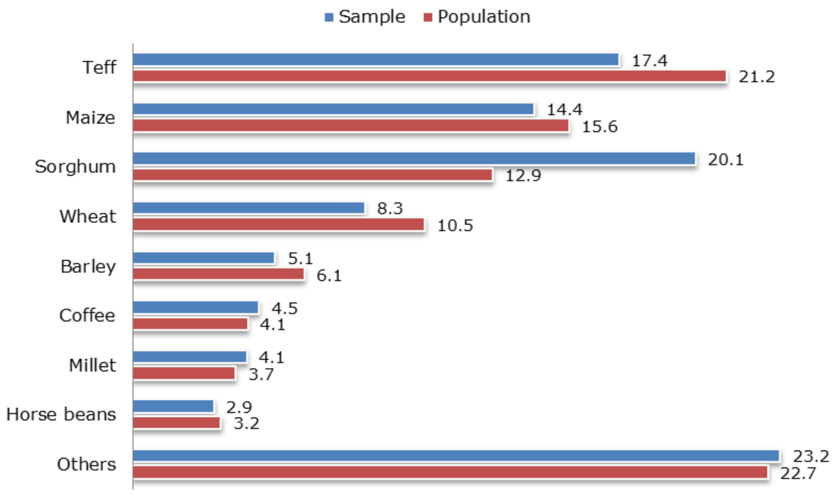
	Amhara	Oromia	SNNP	Tigray	Other regions	Ethiopia
Number of surveyed farm households	618	572	850	295	566	**2,901**
Total crop area, including fallow land (ha)	761.5	1,049.5	722.2	492.9	513.1	**3,539.2**
Total cultivated land area (ha)	713.5	934.2	599.6	475.3	456.2	**3,178.8**
Total production value (thousand ETB)	6,063	6,566	4,047	3,279	4,211	**24,166**
Average farm size (ha, including fallow)	1.23	1.83	0.85	1.67	0.91	**1.22**
Standard deviation of farm size (ha)	0.99	2.77	1.01	5.29	1.21	**2.30**
Average number of fields per household	9.5	11.9	12.8	6.9	7.4	**10.3**
Average field size (ha)	0.13	0.15	0.07	0.24	0.12	**0.12**
	Land use (Meher season, % of total cultivated land by region)					
Sorghum	17.49	8.39	10.03	46.08	34.61	**20.14**
Teff	22.71	21.76	18.26	12.89	3.76	**17.40**
Maize	10.59	16.95	17.69	4.48	20.93	**14.37**
Wheat	9.05	11.89	9.69	6.24	0.13	**8.30**
Barley	8.46	6.23	3.48	4.68	0.05	**5.10**
Coffee	0.21	7.46	7.67	0.00	5.80	**4.52**
Millet	7.06	1.86	0.30	8.34	4.62	**4.10**
Sesame	2.90	1.01	0.29	9.39	5.09	**3.14**
Horse beans	4.59	2.75	4.88	1.07	0.01	**2.92**
Haricot beans	1.62	4.04	3.35	0.19	2.24	**2.53**
Nuegs	2.64	5.23	0.00	0.41	0.56	**2.27**
Chat	0.25	2.18	1.83	0.17	7.72	**2.18**
Enset	0.00	1.07	8.59	0.00	0.17	**1.96**
Field peas	2.21	1.38	3.72	0.42	0.00	**1.67**
Other vegetables	0.69	1.07	4.92	0.10	1.50	**1.62**
Other pulses	2.04	0.76	0.05	0.76	3.67	**1.33**
Other oilseeds	0.68	0.66	0.13	0.08	5.72	**1.20**
Chickpeas	1.49	1.35	0.10	0.88	0.29	**0.92**
Other crops	0.57	0.89	1.04	1.71	0.02	**0.84**
Other spices	0.94	0.90	1.13	0.15	0.67	**0.81**
Other fruits	0.13	0.24	0.98	0.75	1.62	**0.63**
Lentils	1.41	0.66	0.07	0.66	0.00	**0.62**
Linseeds	1.05	0.42	0.02	0.39	0.09	**0.43**
Other cash crops	0.43	0.22	0.47	0.14	0.26	**0.31**
Potatoes	0.68	0.25	0.31	0.01	0.02	**0.29**
Banana	0.03	0.22	0.92	0.02	0.25	**0.28**
Onion	0.08	0.16	0.08	0.00	0.20	**0.11**
All crops	100.00	100.00	100.00	100.00	100.00	**100.00**

Source: ESS 2013/2014.

When applying the ESS sample weights to individual farmers, to obtain population data as representative data of farming activities in Ethiopia, the composition of the main crops changes slightly (Figure 7). In the population data[6] the shares of cultivated area for the main crops teff, maize and wheat increase, while the importance of sorghum cultivated area is largely diminished (from 20.1% to 12.9%). The population shares for cultivated area by crop is, however, fully consistent with the shares of cultivated area derived from the larger AgSS sample that are summarized in Table 2 and Figure 2, confirming that the ESS sample is a representative sub-sample of the AgSS from this perspective.

[6] In contrast to population data, obviously no weighting has been applied to all the sample data that are presented in this report.

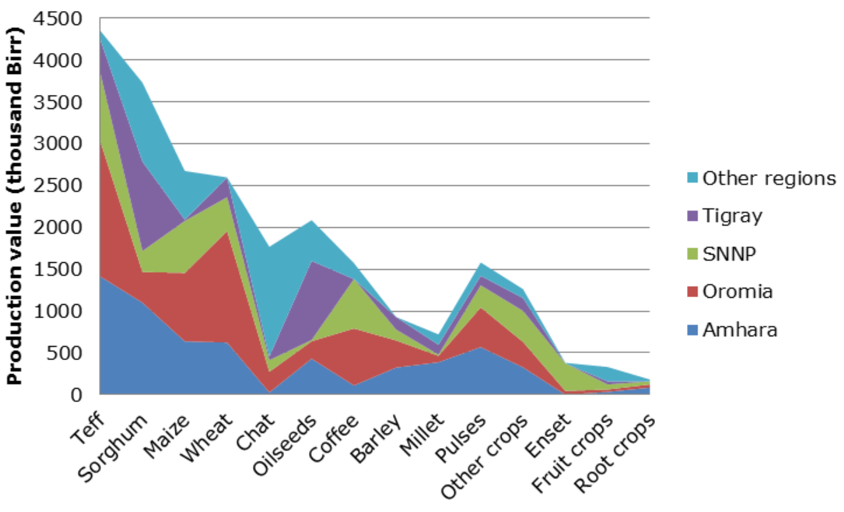
Figure 7: Cultivated area by main crops (% of total): sample vs population



NB: See Table 6 for the sample cultivated area and its further composition by crops.

The total production value of all crops in the sample amounts to ETB 2.4 million, of which 55.3% is from the four main crops: teff (18.0%), sorghum (15.4%), maize (11.1%) and wheat (10.8%). Next in the list of top revenue generators are chat, oilseeds and coffee, which account respectively for 7.3%, 8.6% and 6.5% of total production value. Figure 8 illustrates the details of the sample production value, by crop and by region. It shows, for example, that about 70% of teff production value comes from only two regions of the country, namely Oromia (37.2%) and Amhara (32.5%). Compared with other main regions of Ethiopia, Tigray produces very little maize, while the others contribute in the range of 20% to 32% to total production value of maize. It is also worth noticing that Oromia is the main producer of wheat, generating more than half of its production value in our sample. By contrast, the main agricultural regions of Ethiopia do not contribute much to chat production, as 74.2% of revenue from chat production comes from 'Other regions', including Harari, Somali, Dire Dawa, Gambela, and Benishangul-Gumuz (not indicated in the graph).

Figure 8: Sample crop production value (thousand ETB)



Our sample (arithmetic) average yields (kg/ha) for all 27 crop items are presented in Table 7, along with their corresponding population (weighted) average yields. The population average yields are smaller than their sample counterparts for most of the crops and regions. For the entire country, population average yields for cereals are, on average, 21% less than their sample yields. The corresponding population vs sample average yield differences for pulses, oilseeds, root crops, fruit crops and other crops are, respectively, -27%, -19%, -33%, -42%, and -25%. This indicates that, on average, farm households with high (vs low) yields in the sample are given smaller (vs larger) weights in calculating the corresponding population yields. However, for a few crops this sample-to-population average yield relation is reversed at regional level, except for enset, which also has higher nationwide population average yield (3,787 kg/ha vs 3,086 kg/ha). For example, given the importance of Oromia to wheat production, it is worth mentioning that the population average yield of wheat in Oromia is 9% larger than its sample equivalent: 1,829 vs 1,680 kg/ha. In Amhara, the population average yield for maize is 3% larger than its sample counterpart.

Table 7: Sample and population average yields by crop (kg/ha)

Crop	Amhara	Oromia	SNNP	Tigray	Ethiopia	Amhara	Oromia	SNNP	Tigray	Ethiopia
	Sample (arithmetic) average yields (kg/ha)					Population average yields (kg/ha)				
	Cereals									
Teff	943	846	855	870	879	791	745	724	578	662
Wheat	1,361	1,680	1,461	1,601	1,510	1,266	1,829	1,086	1,132	1,086
Maize	1,907	1,964	1,861	1,711	1,862	1,964	1,525	1,644	1,431	1,533
Sorghum	1,575	1,146	1,221	1,240	1,393	1,318	944	836	1,134	1,168
Barley	1,221	1,412	1,575	1,721	1,434	970	1,036	1,500	1,310	1,096
Millet	1,362	957	1,288	923	1,132	1,176	713	1,164	569	919
	Pulses									
Chickpeas	1,032	1,146	485	1,033	950	912	1,176	201	645	576
Horse beans	1,038	1,198	1,137	1,259	1,132	886	906	740	910	677
Haricot beans	659	848	1,003	583	886	652	252	639	278	704
Field peas	820	665	661	1,152	741	633	656	454	947	634
Lentils	650	637	607	712	655	499	564	344	533	485
Other pulses	1,342	1,136	948	922	1,179	1,291	803	434	1,048	903
	Oilseeds									
Nuegs	372	376		271	366	348	266		218	280
Linseeds	345	504	560	426	407	293	460	254	372	330
Sesame	407	339	231	617	432	476	288	204	571	315
Other oilseeds	310	381	407	244	737	197	327	454	255	696
	Root crops									
Potatoes	6,043	7,038	5,183	3,597	5,811	3,837	3,892	3,622	1,762	3,390
Onion	6,800	7,043	7,794	2,542	8,822	5,469	18,485	4,089	2,899	6,762
	Fruit crops									
Banana	3,474	2,568	3,144	238	3,117	1,780	1,265	1,878	327	1,490
Other fruits	8,306	8,131	6,933	5,608	7,565	7,183	2,533	2,684	3,389	5,135
	Other crops									
Chat	512	567	1,118	1,863	697	321	393	925	886	548
Coffee	1,106	855	1,490	73	1,277	1,409	546	1,301	80	752
Enset		3,247	3,077		3,086		2,731	2,816		3,787
Other cash crops	2,726	2,845	2,964	3,661	3,058	1,549	1,913	2,362	702	2,712
Other spices	1,356	1,905	1,735	2,461	1,667	894	986	1,371	1,674	1,325
Other vegetables	4,541	5,997	5,470	3,279	5,313	1,351	2,279	3,549	2,414	2,775
Other crops	2,001	3,889	4,882	1,965	4,167	1,753	1,369	2,894	1,646	1,990

Source: ESS 2013/2014 and authors' calculations.

Improved seed use

The regional and nationwide use of conventional and improved seeds in our sample is presented in Table 8. Farmers mostly use conventional seeds, and as expected improved seeds are used only for growing cereals, for which such seeds are available. Among all the non-cereal crops, conventional seeds are used mostly for pulses and vegetables.

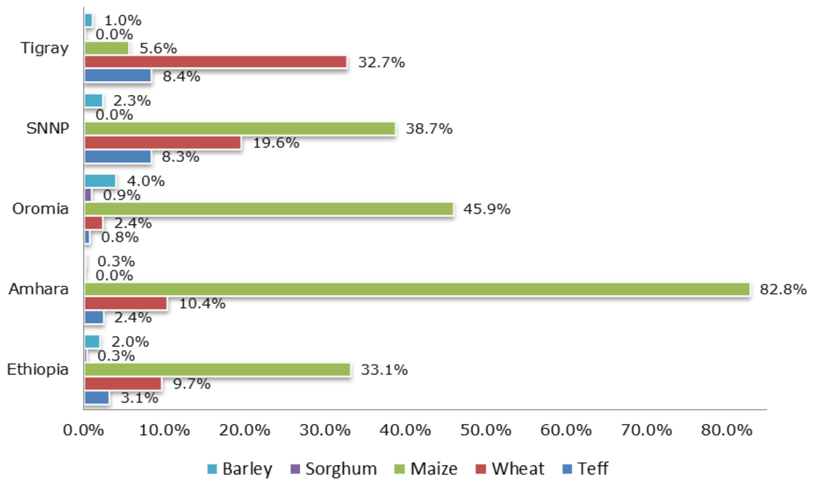
Table 8: Absolute amount of conventional and improved seeds used by the sample (kg)

Crops	Amhara		Oromia		SNNP		Tigray		Ethiopia	
	Conv. seed	Impr. seed	Conv. seed	Impr. seed	Conv. seed	Impr. seed	Conv. seed	Impr. seed	Conv. seed	Impr. seed
Teff	5,770	139	10,993	83	3,817	317	2,300	193	23,296	732
Wheat	8,960	931	22,582	537	7,659	1,500	3,598	1,177	42,858	4,145
Maize	1,098	909	4,000	1,837	2,462	952	826	46	11,984	3,971
Sorghum	2,715	1	1,830	17	1,390	0	3,057	0	13,159	43
Barley	10,082	26	10,075	400	2,550	59	3,840	40	26,574	524
Millet	3,022	0	563	0	60	0	1,386	0	5,659	0
Pulses	11,131	0	10,209	0	5,202	0	1,847	0	30,573	0
Oilseeds	1,044	0	1,189	0	102	0	539	0	5,316	0
Potatoes	4,322	0	905	0	1,681	0	67	0	7,041	0
Onion	787	0	74	0	727	0	4	0	2,334	0
Other spices	622	0	192	0	815	0	68	0	1,904	0
Other vegetables	657	0	2,428	0	8,830	0	26	0	12,635	0
Other crops	495	0	2,165	0	1,523	0	1,484	0	5,703	0

NB: Conventional and improved seeds are indicated, respectively, by 'Conv. seed' and 'Impr. seed'. *Source*: ESS 2013/2014 and authors' own calculations.

For the entire country, the use of improved seeds is particularly significant for maize, making up 25% of maize total seeds use (equivalently, the ratio of improved to conventional seeds use is 33.1% for maize, see Figure 9). However, there is considerable heterogeneity by region. In Amhara, improved seed use for maize is equivalent in size to 82.8% of conventional seed use. This proportion is also high for Oromia (45.9%) and SNNP (38.7%). However, as shown in Figure 9, farmers in Tigray and SNNP also use a considerable amount of improved seeds, compared with other regions.

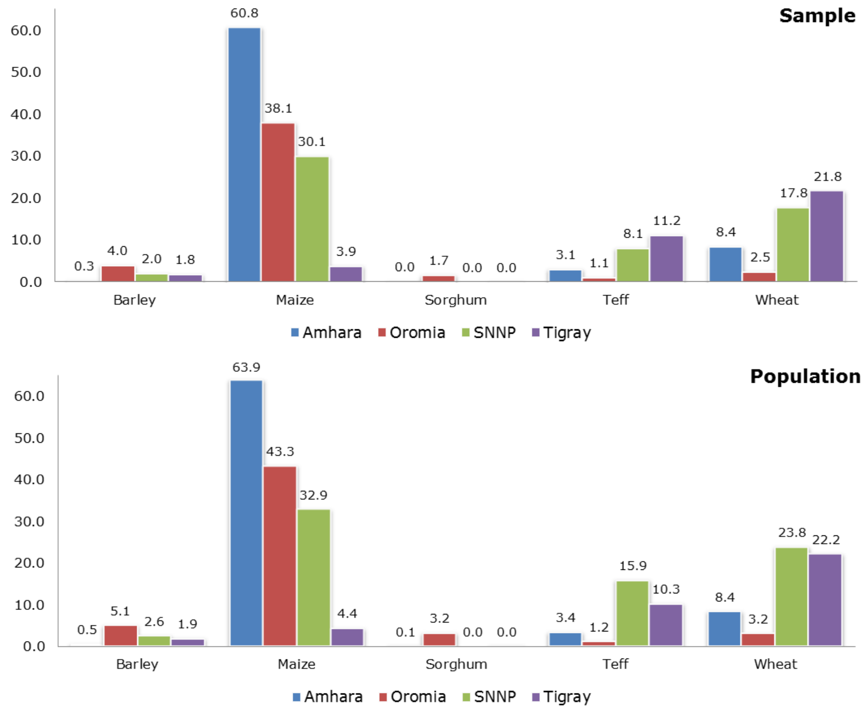
Figure 9: Ratios of improved to conventional seed use in the sample (in %)



In terms of area in the sample, improved seed was applied to only 5.7% of the total area. Figure 10 shows the improved seed area as a percentage of total area in each main region of Ethiopia, both for the sample and population data. Consistent with the conclusions derived above, maize is the crop for which improved seed is most relevant in terms of area applied. For example, it follows from Figure 10 that improved seed was applied to 63.9% of the total maize area in Amhara region in our population data (hence, the remaining 36.1% of maize growing area was covered by conventional seeds). After Amhara, improved seed was used on relatively large proportions of (population) land in Oromia (43.3%) and SNNP (32.9%). For wheat production, improved seed area was of roughly equal proportion to total population wheat areas in SNNP (23.8%) and Tigray (22.2%).

One can observe from Figure 10 that there are some (generally non-significant) deviations in improved seed area proportions by region between the sample and population data. For example, while the proportion of improved seed area in SNNP's total teff cultivated area is 8.1% in the sample, the corresponding population figure is almost double, rounding to 16%. This reflects the fact that farmers using improved seeds in SNNP have, on average, larger weighting in generating the population data than the farmers not using improved seed. Nonetheless, the sample and population improved seed area data provide equivalent information in terms of relative size of improved seed area, by cereal crop and by region (i.e. the correlation coefficient of these two data is 0.993).

Figure 10: Sample and population improved seed area in each region (in %)



There are many different varieties of hybrid maize, with more than 20 varieties mentioned in the ESS survey. Yet, as presented in Table 9, the most frequently used varieties in the sample are BH660 (40.7%), BH540 (15.6%) and BH140 (6.1%). It is remarkable that a large share of farmers (16.1%) reported not knowing or remembering which hybrid seed they had used.

Table 9: Hybrid maize varieties in the sample

Hybrid maize varieties	No. of observations	%
BH660	172	40.7
BH540	66	15.6
BH140	26	6.1
AWASA	14	3.3
AGAR	10	2.4
BH542	8	1.9
SHONE	7	1.7
BH543	5	1.2
FENAR	5	1.2
Other varieties	42	9.9
Don't know	68	16.1
Total	423	100.0

Source: ESS 2013/2014

Fertilizer use

We first report absolute values for fertilizer use, by crop, to find out the main crop destination of inorganic fertilizer, and then move onto the description of our sample fertilizer intensity rates. The total amount of fertilizer use in our sample was 123,531 kg, which was dominated by DAP (62%), while the remaining 38% was urea. About 71% of total fertilizer was used for only three cereals: teff (28.5%), maize (21.8%) and wheat (20.6%). Together with sorghum (6.4%), barley (6.7%) and millet (4.6%), cereals overall account for 88.6% of fertilizer use. DAP is also used more than urea for most crops (Figure 11 and

Table 10).

Figure 11: Sample total fertilizer use by crop (in kg)

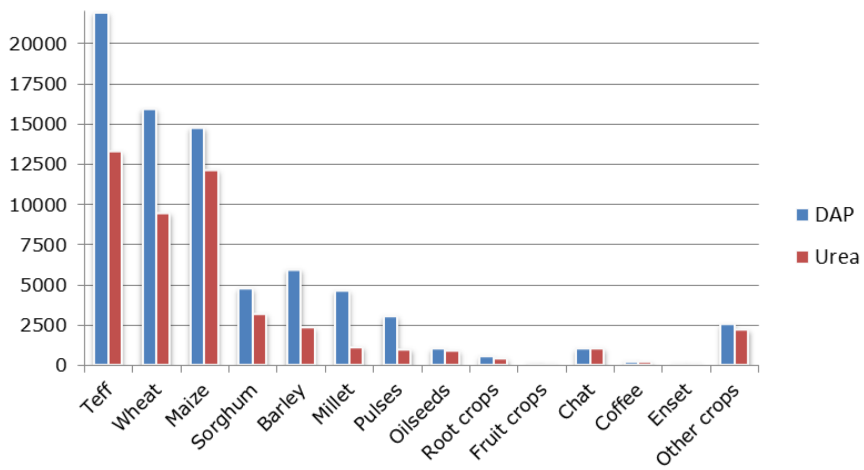


Table 10: Sample fertilizer use by region (kg)

Crops	Amhara		Oromia		SNNP		Tigray		Oth. regions		Ethiopia	
	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea	DAP	Urea
Teff	5,347	3,710	9,636	7	4,435	2,409	2,390	1,696	5,459	143	21,951	13,282
Wheat	3,066	2,174	8,275	2	3,274	1,773	1,314	1,303	4,216	6	15,935	9,469
Maize	5,990	5,082	4,072	877	3,376	2,548	447	475	3,145	884	14,769	12,127
Sorghum	108	211	549	655	317	253	3,175	1,577	484	619	4,768	3,181
Barley	1,534	324	2,682	6	729	362	992	831	791	10	5,947	2,314
Millet	3,201	466	245	0	59	20	1,043	619	6	61	4,609	1,111
Pulses	696	155	1,138	11	951	217	176	124	465	71	3,032	973
Oilseeds	372	294	254	142	0	0	305	188	247	64	993	870
Root crops	117	62	237	18	158	96	5	3	216	6	523	395
Fruit crops	1	4	9	39	12	2	0	14	3	71	93	61
Chat	0	0	289	726	28	28	0	0	261	668	986	1,015
Coffee	0	0	108	5	86	83	0	0	67	6	200	156
Enset	0	0	3	0	21	52	0	0	1	0	24	53
Other crops	530	574	954	71	454	294	466	484	761	107	2,511	2,185
Total	20,962	13,057	28,450	2,558	13,900	8,137	10,313	7,315	16,124	2,715	76,340	47,191

Source: ESS 2013/2014 and authors' calculations.

At the regional level, Amhara and Oromia account for, respectively, 28% and 25% of the sample total fertilizer use. Compared to other regions, in Oromia and 'Other regions' very little urea is used for teff and wheat. Recall that the recent tendency in fertilizer use in Ethiopia is substitution of DAP with urea, NPS, or NPS plus urea (Figure 3). However, this recent change in fertilizer preferences of farmers is not captured in our data, which contain only detailed information on DAP and urea.

Finally, Table 11 presents average fertilizer rates, by crop and region, for our sample, i.e. fertilizer use (in kg) per ha of fertilized land. Here, instead of examining the intensities of the two types of fertilizers separately, their combined intensities in terms of nitrogen use are presented (for details of this derivation, see section 4.4). Although our sample fertilizer intensities are more or less in line with the corresponding average intensities derived from the AgSS survey (Figure 4), the two are not entirely comparable because: (a) total fertilizer in deriving the AgSS intensities equals the simple sum of all types of fertilizers, while nitrogen intensities in Table 11 are the weighted average of the individual fertilizer rates; and (b) AgSS intensities represent fertilizer per total cultivated land, irrespective of being fertilized or not, while our sample fertilizer intensity rates apply to fertilized land only.

Table 11: Sample average nitrogen use per ha of fertilized land (kg/ha)

Crops	Amhara	Oromia	SNNP	Tigray	Other regions	Ethiopia
Teff	30.8	33.0	32.6	29.1	6.5	31.1
Wheat	47.3	42.6	40.8	44.9	30.7	43.8
Maize	60.1	43.0	43.2	45.3	38.2	47.9
Sorghum	28.5	24.6	30.4	25.9	27.3	27.0
Barley	27.8	33.0	40.5	37.7	36.2	35.0
Millet	22.5	11.0	23.6	29.5	2.6	23.0
Pulses	33.2	31.8	25.8	27.7	12.8	28.7
Oilseeds	30.5	27.2		46.8	18.6	30.5
Root crops	47.8	53.1	29.5	52.2	56.6	46.9
Fruit crops	44.9	36.7	25.6	48.4	44.6	34.9
Chat	28.9	34.0	27.6		39.5	37.1
Coffee	40.7	24.6	33.0	20.8	36.3	31.0
Enset		25.2	29.5			28.4
Other crops	49.2	37.1	56.2	54.7	43.0	47.3

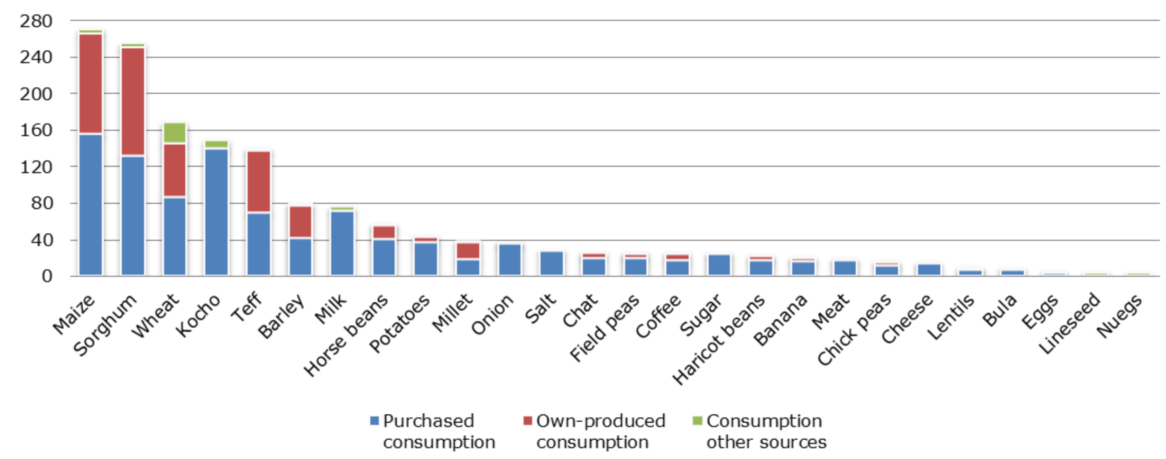
Source: ESS 2013/2014 and authors' calculations.

Consumption

Cereals are the most consumed food items in Ethiopia. Country-level annual average total consumption per household of the top five food items in our sample are: maize (271.1 kg/year), sorghum (255.5 kg/year), wheat (168.7 kg/year), kocho (149.1 kg/year) and teff (139.3 kg/year). For all 26 food categories, on average 76.5% of total consumption comes from purchases, 19.4% from own production, and the remaining 4.1% comes from gifts and other sources. These details by food items are given in Figure 12. For cereals (maize, sorghum, wheat, teff, barley and millet), on average 51.4% of total consumption comes from purchases, 45% from own production, and the rest (3.7%) from other sources.

Kocho and bula are two Ethiopian staples that are made from the same starchy plant – enset (also called false banana as this plant resembles banana tree but yields no bananas). Evidently, kocho is also an important food category in Ethiopia; 94% of it is purchased and the rest comes from gift and other sources.

Figure 12: Sample average food consumption by source (kg per year)



Absolute, and average per household, annual amounts of consumption by source, together with production and sale data in the sample, by food category, are presented in Table 12. For each food item (at all levels of aggregation), the source and use quantity balance holds, i.e. Production + Purchased consumption +

Consumption from other sources = Total consumption + Sale, where Total consumption includes all three sources of consumption. The sample sale-to-production ratios are smallest for barley (0.39), horse beans (0.43), sorghum (0.47), teff (0.48), banana (0.50) and potatoes (0.50). That is, for these crops at least half of farmers' production is consumed in-house: e.g. for barley, own-produced consumption makes up 61% of its production at the country level. At the other extreme, over 80% of coffee, linseeds, nuegs and onion is produced for sale purposes: own consumption of these crops in the sample equates to, respectively, 20%, 16%, 9% and 4% of production.

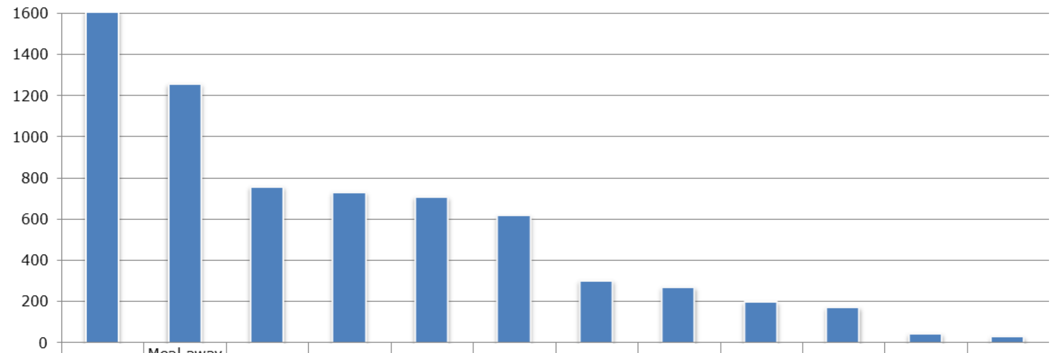
Table 12: Production, sale and consumption by source, sample data

	Prod.	Sale	Purch. cons.	Own cons.	Cons. other	Prod.	Sale	Purch. cons.	Own cons.	Cons. other
	Total amount (kg per year)					Household average (kg per year)				
Barley	172,189	67,979	117,434	104,211	6,015	59.71	23.57	40.72	36.13	2.09
Maize	669,114	349,580	448,435	319,534	13,877	232.01	121.21	155.49	110.80	4.81
Millet	118,633	62,693	50,763	55,940	1,305	41.13	21.74	17.60	19.40	0.45
Sorghum	651,863	309,146	380,634	342,717	13,421	226.03	107.19	131.98	118.83	4.65
Teff	377,689	179,693	199,021	197,996	4,676	130.96	62.31	69.01	68.65	1.62
Wheat	374,814	202,107	248,355	172,707	65,431	129.96	70.08	86.11	59.88	22.69
Chickpeas	26,655	14,729	30,640	11,926	731	9.24	5.11	10.62	4.14	0.25
Haricot beans	33,362	21,993	50,396	11,369	2,017	11.57	7.63	17.47	3.94	0.70
Horse beans	75,711	32,241	115,555	43,471	4,452	26.25	11.18	40.07	15.07	1.54
Lentils	10,351	7,333	19,274	3,019	1,934	3.59	2.54	6.68	1.05	0.67
Field peas	29,391	15,455	55,595	13,937	3,980	10.19	5.36	19.28	4.83	1.38
Linseed	4,798	4,016	5,019	781	573	1.66	1.39	1.74	0.27	0.20
Nuegs	19,033	17,240	2,508	1,794	209	6.60	5.98	0.87	0.62	0.07
Banana	15,753	7,870	47,128	7,883	1,588	5.46	2.73	16.34	2.73	0.55
Onion	38,208	36,700	100,746	1,508	881	13.25	12.73	34.93	0.52	0.31
Potatoes	37,056	18,651	104,074	18,406	2,571	12.85	6.47	36.09	6.38	0.89
Chat	35,534	21,291	57,124	14,244	3,453	12.32	7.38	19.81	4.94	1.20
Coffee	106,399	84,626	48,013	21,773	1,253	36.89	29.34	16.65	7.55	0.43
Kocho	0	0	402,655	0	27,333	0.00	0.00	139.62	0.00	9.48
Bula	0	0	19,826	0	3,820	0.00	0.00	6.87	0.00	1.32
Meat	0	0	49,858	0	1,339	0.00	0.00	17.29	0.00	0.46
Milk	0	0	205,844	0	12,557	0.00	0.00	71.37	0.00	4.35
Cheese	0	0	37,854	0	1,287	0.00	0.00	13.13	0.00	0.45
Sugar	0	0	68,458	0	212	0.00	0.00	23.74	0.00	0.07
Salt	0	0	77,660	0	99	0.00	0.00	26.93	0.00	0.03
Eggs	0	0	9,525	0	309	0.00	0.00	3.30	0.00	0.11

NB: 'Prod.', 'Purch. cons.', 'Own cons.' and 'Cons. other' denote, respectively, production, purchased consumption, consumption from own production, and consumption from gifts and other sources. Source: ESS 2013/2014 and authors' calculations.

The sample average non-food and other food expenditures (reported in ETB) are presented in Figure 13. Clothing and shoes are the most important non-food expenditures in Ethiopia, where farm households spend on average per year ETB 1,611 (approximately EUR 61.7, using the 2014 average exchange rate of 26.1143 ETB/EUR). Average annual expenditure on meals away from home (breakfast, lunch and dinner, which includes full meals such as *enjera* made of teff/millet/barley with any type of stew, *kocho/kocho* with meat, rice with sauce, etc.) is ETB 1,257 (approximately EUR 48.1). Other expenses include expenditure on matches, batteries, candles, laundry and hand soaps, other personal care goods, IDDIR contributions and church donations. Recreation includes ceremonial expenses (weddings, birthdays and funeral expenses), which is another important non-food expenditure item. About 85%, 63% and 53% of households living in, respectively, rural areas, small towns and large towns pay taxes and levies (CSA and LSMS, 2015a). On average, rural households in our sample pay ETB 198 (approximately EUR 7.5) per year in taxes, which is comparable to ETB 167 reported in CSA and LSMS (2015a). It is also reported that households in small town areas and large towns paid, on average, ETB 802 and ETB 1,635, respectively.

Figure 13: Sample average non-food and other food expenditures, Ethiopia (ETB/year)



	Clothing & footwear	Meal away from home	Beverage & tobacco	Other expenses	Recreation	Transp. & commun	Rent & fuel	House operations	Taxes and levies	Education	Fruits & vegetables	Dairy
Ethiopia	1611	1257	758	731	708	617	302	269	198	172	43	28

The regional composition of consumption of all FSSIM-Dev food and non-food items is given in Figure 14, which shows quite some heterogeneity in consumption across different regions of Ethiopia. For example, very little millet is consumed in SNNP, because in this region production of millet is almost non-existent (the share of SNNP production is only 1.87% and 0.67% of the country total millet production in our sample and population, respectively). On the other hand, kocho and bula are consumed mainly in SNNP because it is the region where most enset is planted (SNNP accounts for 81.6% and 70.0% of Ethiopia enset production in our sample and population data, respectively). In the same vein, little maize is consumed in Tigray (only 2.53% of total maize consumption in population data), although it is an important cereal in the country, taking first position in terms of nationwide crop production.

Finally, the average sale and purchase prices in our sample are reported, respectively, in Table 13 and Table 14. These prices are used in the model and given here for illustrative purposes. We provide the regional details on sale prices (at farm gate) since they are an important factor for the income generation capability of market-oriented farmers, but the country-level average and variation statistics for purchase prices. Note that there are more purchase price categories as, in addition to non-aggregate crop prices, these include prices for kocho and bula (instead of enset from the production side), meat, milk, cheese, sugar, salt and eggs.

Figure 14: Regional shares of households' average food and non-food consumption (%)

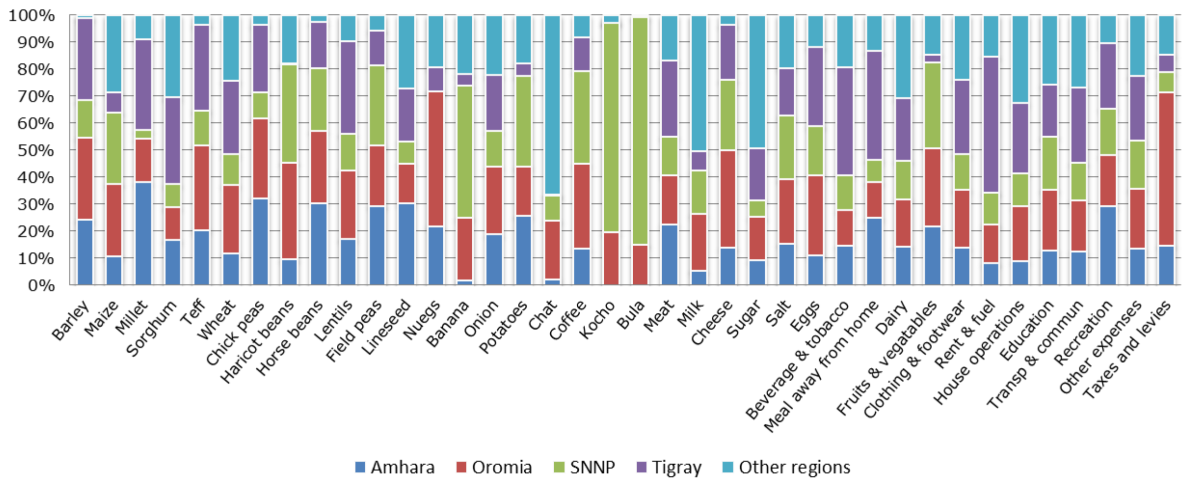


Table 13: Sample average sale prices by region (ETB per kg)

Crop	Amhara	Oromia	SNNP	Tigray	Other regions	Ethiopia
			Cereals			
Teff	11.44	11.49	11.09	11.53	11.90	11.39 (2.35)
Wheat	8.22	6.53	6.78	6.89	6.70	7.21 (1.35)
Maize	4.63	3.75	4.06	0.40	4.23	3.85 (1.87)
Sorghum	7.68	5.18	4.29	5.43	5.79	5.76 (1.66)
Barley	5.38	5.64	5.29	4.89	5.60	5.34 (1.43)
Millet	6.84	6.09	6.39	4.22	6.07	5.91 (1.96)
			Pulses			
Chickpeas	7.08	7.57	7.65	7.56	7.65	7.38 (0.98)
Horse beans	6.53	7.07	5.99	8.52	6.50	6.68 (1.93)
Haricot beans	11.85	9.52	6.32	7.12	7.23	8.10 (2.50)
Field peas	7.09	7.03	7.04	8.19	7.00	7.13 (1.77)
Lentils	11.67	11.61	10.67	13.05	0.00	11.84 (2.76)
Other pulses	4.86	5.04	6.02	5.18	6.46	5.19 (1.99)
			Oilseeds			
Nuegs	10.17	10.06		8.75	9.16	9.98 (1.35)
Linseeds	9.71	10.91	8.01	9.62	10.53	9.96 (1.74)
Sesame	31.19	18.13	26.28	37.02	33.96	32.07 (7.83)
Other oilseeds	7.30	5.15	6.59	13.00	6.58	6.54 (2.58)
			Root crops			
Potatoes	3.08	2.75	4.00	2.25	3.36	3.37 (0.99)
Onion	8.83	5.83	6.41	6.00	4.20	6.49 (2.78)
			Fruit crops			
Banana	9.54	3.66	2.40	2.25	2.97	2.95 (2.18)
Other fruits	4.64	3.17	2.76	3.70	5.31	3.72 (2.12)
			Other crops			
Chat	51.99	36.18	16.40	57.83	123.59	71.52 (43.07)
Coffee	63.17	18.28	11.27	12.00	11.44	15.14 (11.83)
Enset		1.74	2.49		2.73	2.38 (0.71)
Other cash crops	14.04	7.21	2.88	12.76	3.60	7.72 (6.48)
Other spices	16.08	11.18	10.33	18.83	12.05	13.13 (7.52)
Other vegetables	8.57	5.25	2.48	7.64	3.63	3.88 (3.52)
Other crops	7.82	5.45	2.70	9.32	4.33	4.24 (2.93)

NB: Figures in parenthesis represent standard deviations for sale prices across Ethiopia.
Source: ESS 2013/2014 and authors' calculations.

Among cereals, teff has the highest average price - approximately ETB 11.4 per kg. Hence, farmers should have an incentive to produce more teff, at least from a theoretical point of view of profit maximization and in the absence of any limiting factor. Average teff prices are more or less the same across Ethiopian regions. Generally, chat is the most expensive crop, followed by sesame and coffee. However, in our sample, chat prices are also the most variable: the coefficient of variation (CV) for chat purchase prices is 0.59, which is larger than the average CV for all 26 purchase prices (0.22) by a factor of 2.6. Relative variability of purchase prices is also high for coffee (with CV of 2.0), salt (1.9), banana (1.7) and potatoes (1.5). On the other hand, the least variable purchase prices (CV ≤ 0.5) are observed for cheese, lentils, bula, nuegs, millet and eggs. The average CV for the purchase prices of the main (six) cereals is 0.17, which is 24% lower than the average CV for all the prices. The relative variability of purchase prices for teff, wheat and maize is lower than the average CV for all the purchase prices by 37%, 19% and 12%, respectively.

Table 14: Sample country-level average purchase prices (ETB per kg)

	Purchase prices	Standard deviation	Coefficient of variation
Barley	6.83	1.08	0.16
Maize	5.64	1.11	0.20
Millet	6.06	0.32	0.05
Sorghum	5.77	1.70	0.29
Teff	12.24	1.72	0.14
Wheat	8.32	1.50	0.18
Chickpeas	11.90	2.65	0.22
Haricot beans	9.94	2.52	0.25
Horse beans	10.57	3.07	0.29
Lentils	23.98	2.12	0.09
Field peas	11.64	2.78	0.24
Linseeds	13.98	2.28	0.16
Nuegs	11.02	0.72	0.07
Banana	8.77	3.29	0.37
Onion	11.08	2.94	0.27
Potatoes	7.34	2.52	0.34
Chat	45.47	26.61	0.59
Coffee	52.68	23.31	0.44
Kocho	4.00	0.67	0.17
Bula	12.03	0.99	0.08
Meat	80.92	18.94	0.23
Milk	9.12	1.94	0.21
Cheese	26.46	2.72	0.10
Sugar	21.60	4.03	0.19
Salt	6.81	2.84	0.42
Eggs	33.35	0.99	0.03

Source: ESS 2013/2014 and authors' calculations.

Off-farm income

The ESS survey includes data on several categories of off-farm income. In Table 15, we present four main sources of farm household income for our sample: income from labour activities (main job, secondary job, temporary job); income from and payments related to operating non-farm enterprise; other income (transfers and gifts, pension and investment income, rental income, other income); and assistance from government and non-governmental agencies (cash, food, and in-kind assistance). Profit from non-farm enterprise operation was calculated as revenue minus operating costs, the latter including expenses for wages, purchase of goods for sale, raw materials and transportation. Table 15 summarizes the relevant data only for those households that reported non-zero income (or payment) items, which was on average only 5.34% of all 2,886 households in the sample.

Table 15: Sample average annual off-farm income, by source and region (ETB)

Income category	Amhara	Oromia	SNNP	Tigray	Other regions	Ethiopia				Number of HHs with non-zero reports
						Average	Min	Max	Std.dev.	
Income from labour activities										
Wages and salary from the main job	8,139	12,587	14,180	18,844	11,532	12,570	17	230,400	23,721	195
Allowances or gratuities, including in-kind payments (uniform, housing, food and transport), from the main job	1,089	1,479	959	3,300	2,076	1,725	75	5,760	1,555	29
Wages and salary from the secondary job		7,600	1,867	1,800	1,247	2,575	200	529,200	124,157	18
Allowances or gratuities, including in-kind payments (uniform, housing, food and transport), from the secondary job					450	450	300	600	212	2
Income from temporary work for the PSNP	1,569	1,789	1,108	1,917	2,385	1,892	2	15,800	1,710	292
Income from other temporary labour work	2,986	3,315	1,430	2,221	2,991	2,669	5	64,800	6,105	358
Income from (and payments related to) operating non-farm enterprise										
Borrowing for non-farm enterprise	2,199	1,518	1,177	5,489	2,222	2,073	20	10,000	2,606	105
Repayment of loans for non-farm enterprise	1,629	1,064	1,207	3,933	1,503	1,581	2	10,000	2,088	91
Profit from non-farm enterprise operation	5,408	3,763	-7,495	-915	13,028	2,843	-475,700	844,636	48,978	703
Other income										
Incoming transfers and gifts from friends/relatives	4,200	1,865	1,963	3,282	2,424	2,695	5	56,500	5,842	404
Pension, interest and other investment income	3,031	655	1,781	2,600	20,000	2,761	15	36,000	6,056	50
Income from renting shop/store/house/car/truck/other vehicles, land, agricultural tools, transport animals	1,457	2,031	1,389	1,816	2,573	1,691	20	16,200	2,094	262
Income from sales of assets (real estate, agricultural and non-agricultural assets)	15,350	413	1,910	4,253	6,779	3,850	100	50,000	8,565	88
Other income: inheritance, lottery, gambling winnings	5,066	30,000	50	500	5,000	6,158	50	30,000	10,512	14
Assistance from governmental and non-governmental agencies										
Cash assistance from PNSP (does not include PNSP labour activities)	818	1,380	703	402	686	654	18	3,000	596	87
Food assistance from PNSP	627	300	310	1,259	1,814	1,385	70	12,660	1,679	89
Other in-kind assistance from PNSP			320	300	881	652	2	1,500	635	5
Other (non-PNSP) cash assistance received by the household	1,337	1,152	717	849	1,777	1,205	80	14,401	1,890	64
Other (non-PNSP) food assistance	486	735	500	968	1,175	968	12	6,700	1,042	195
Other (non-PNSP) in-kind assistance	326	360	727	200	335	402	1	2,040	437	33
Average number of households reporting non-zero off-farm income (average across all income and payment categories)	39.4	27.3	42.4	36.7	19.8	154.2	154.2	154.2	154.2	154.2
Total number of households in the sample	617	570	563	843	293	2,886	2,886	2,886	2,886	

Source: Authors' calculations from FSSIM-Dev sample of rural farmers based on the 2013/14 ESS survey. 'HHs' stands for 'households'.

The largest participation rate is observed for reporting revenue and operating expenses related to non-farm enterprise (NFE) operation: 24.4% of households reported the corresponding items. Indeed, NFEs play an important role in the lives of Ethiopian households, and nationally about 28% of households own one or more NFEs, which are more common in urban than in rural areas. CSA and LSMS (2015a) report that 60%, 34% and 26% of households in, respectively, large town areas, small town areas and rural areas own one or more NFEs. The three most important NFE activities in each area (rural or urban) are: non-agricultural businesses or services from home (including shops); selling of processed agricultural products (including food and beverages); and trading business such as selling goods on a street or in a market.

About 7% of households in our sample reported income from a main job – wage, salary, commission or any payment in kind for being employed in any kind of job, including part-time labour, by anyone who was not a member of the household. Nationally, the sample average annual income from the main job was ETB 12,570 (approximately EUR 481 at the time). Similarly, 10.1% of households also reported income from temporary work for the Productive Safety Net Programme (PSNP), and 12.4% from other temporary/casual labour work, in the past 12 months. Nationwide, average income from this amounted to ETB 1,892 and ETB 2,669, respectively.

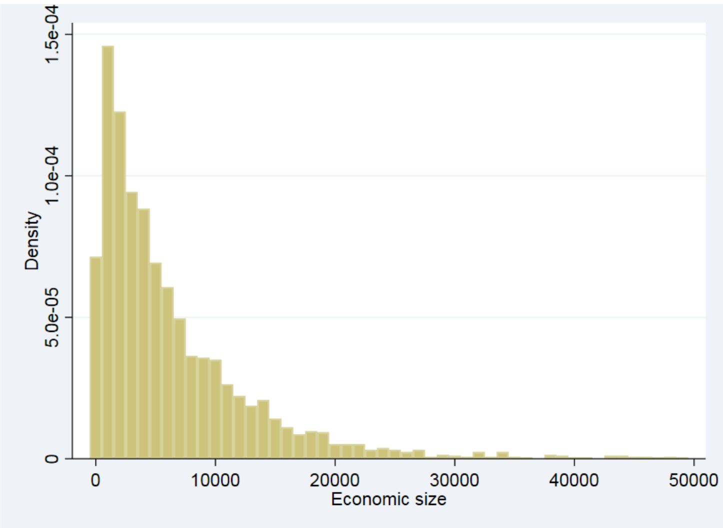
Food and non-food transfers were received by 14% of households in our sample, with an average value of ETB 2,695 throughout the country. With the exception of rental income (9.1% of households), other sources in the category 'Other income' were reported by very few households (0.5% to 1.7%).

About 3% of households reported receiving (cash and/or food) assistance under the PSNP. Households do also receive non-PSNP food and non-food assistance, for free or in association with inputs for work programmes or food for work. Non-PSNP food assistance was reported by about 7% of households; the value of this is, on average, higher in 'Other regions' than in the main agricultural regions of Ethiopia.

4.3 Farm household typology

Farm types are defined within each region, aiming to group farmers into homogeneous groups such that the above assumptions on gross margins and behavioural function parameters for alternative activities are as plausible as possible. Farm types have been defined based on a combination of farms' crop specialization and economic size. The crop specialization has been determined based on each crop's contribution to the *total standard output* of the farm. The standard value of crop production corresponds to the average yield for each crop (in this case the yield for the 2013/14 *meher* season), valued at actual farm-gate prices (in this case the farm-gate price[7] for 2014). This provides the standard output by crop, in ETB per ha. The economic size of a farm is then determined by the total standard output given its crop allocation. The distribution of the economic size of farms in the survey is presented in Figure 15.

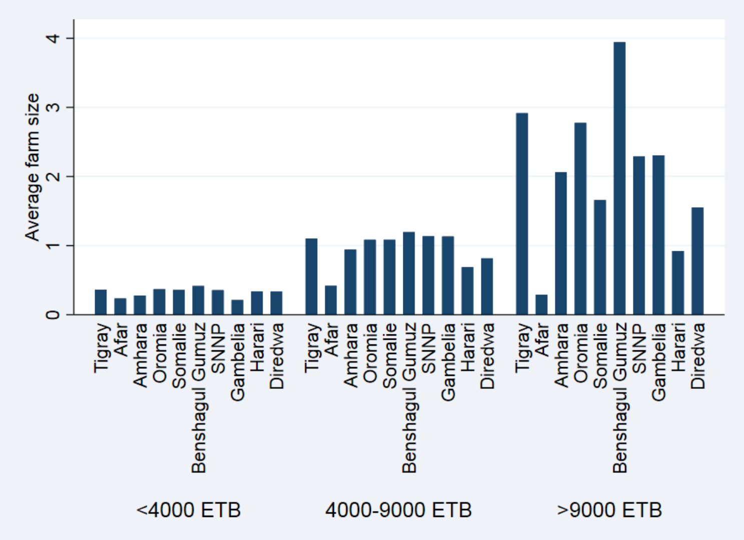
Figure 15: Distribution of farms according to their economic size



[7] Individual farm-gate prices were derived from sales quantities and values reported in the 2013/14 LSMS-ISA survey. Outliers were removed and missing prices were replaced by the average price at village- or higher administrative level, depending on the number of price observations available.

Based on this distribution, farms have been classified into three different categories of economic size: < ETB 4,000 (subsistence farms), ETB 4,000-9,000 (small farms), and > ETB 9,000 (medium-large farms). Figure 16 illustrates the correlation of our measure of economic size with cultivated area. For each of the regions, average farm size is illustrated for each of the three economic size groups.

Figure 16: Average farm size by economic size (in ETB) and region



Given that there are considerable differences in type of farming, depending on the type of crops cultivated, a second categorization is made based on the importance of different crop types in total standard output. The following crop types are considered: field crops (cereals, legumes, oilseeds and root crops), horticulture (vegetables and spices), permanent crops (fruits, coffee, chat, sugarcane and other permanent crops), and a group of mixed farms. Field crops are by far the most important crop category in Ethiopia and 95% of farm households in the survey cultivate at least one field crop. For 74.5% of households, field crops constitute at least 50% of total standard output. The categories identified are illustrated in Table 16. Given that horticulture specialists make up only a very small part of the sample, they were merged with mixed farms for the estimation of parameters.

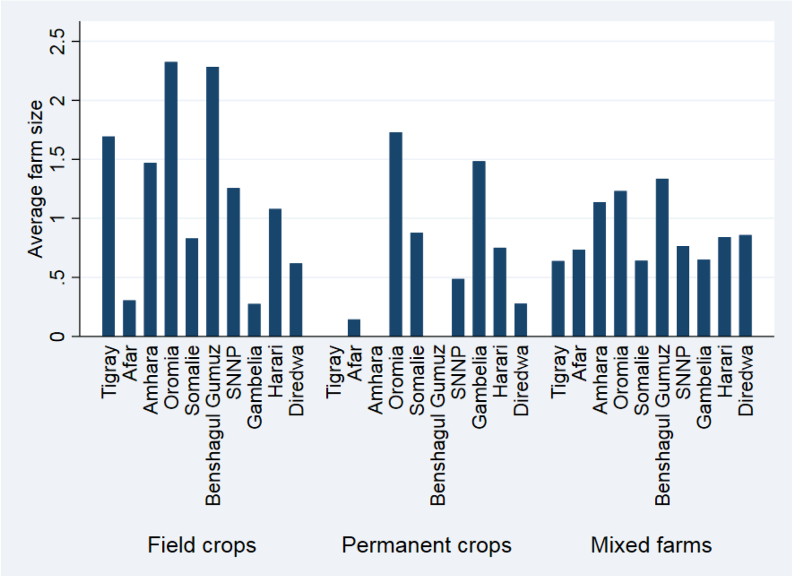
Table 16: Farm specialization categories

Categories	Farm specialization category	
FS100	Specialist in field crops (cereals, legumes, oilseeds and roots combined)	Field crops ≥ 80% of total standard output (SO)
FS200	Specialist in horticulture	Horticulture crops ≥ 50% of total SO
FS300	Specialist in permanent crops	Permanent crops ≥ 50% of total SO
FS400	Mixed farms	None of the above

Figure 17 illustrates average farm size by farm specialization and region, from which one may conclude that specialist field crop farms tend to have a larger farm size.

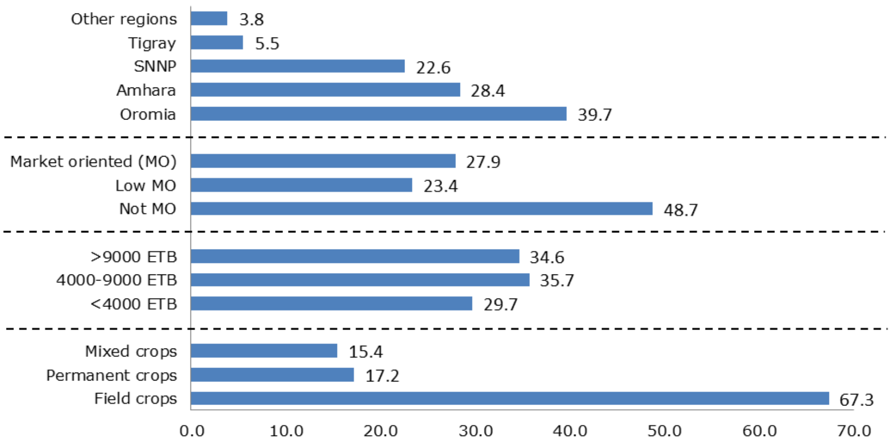
In addition to farm specialization and economic size, farms have also been classified into three different categories according to their degree of orientation into the market, using the share of total output that is marketed: 1) not market oriented (0% marketed); 2) low market orientation (< 10% marketed); 3) market oriented (> 10% marketed).

Figure 17: Average farm size by farm specialization category (LSMS-ISA, 2013/14)



The total number of farms in our population data for FSSIM-Dev is 12,230,785. Figure 18 illustrates the corresponding population distribution (shares) of farms, by region, market orientation, economic size, and specialization category. Almost 40% of farms are located in Oromia, which together with Amhara accounts for 68% of farms in our data. Almost half (49%) of the farms do not offer their output in the market, while about 28% of farms are market oriented, i.e. the share of their total output marketed is larger than 10%. In terms of economic size, the share of subsistence farms is 30%, while that of small farms and medium-large farms is roughly the same - 35% in each case.

Figure 18: The distribution of farm types in FSSIM-Dev population data (%)



4.4 Crop-yield response function to nitrogen fertilizer

The response of crop yields to fertilizer application in the model is based on a simple nitrogen response function that was estimated for each crop, relying on the yields and fertilizer use reported in the ESS survey.

As already discussed in section 2.5, the most commonly applied fertilizers in Ethiopia at the time of the survey were DAP and urea. Data on fertilizer use in the ESS survey consists of the quantity of DAP and urea applied, as well as the quantity and value of DAP and urea purchased. Given that the composition of DAP includes 18% nitrogen (N) and 46% phosphorus pentoxide (P_2O_5), and urea is 46% N, the quantity of nitrogen applied is derived as *N = 0.18 * (quantity DAP) + 0.46 * (quantity urea)*.

The crop yield response to fertilizer use has been implemented for all crop categories with a minimum number of observations on fertilizer use. A separate response function is implemented for conventional and for improved seeds, if the number of observations allows for such separate estimation.

The fertilizer response functions were derived in two steps. In the first step, for each of the crop categories in the FSSIM-Dev model, a simple regression analysis was performed to obtain the yield response to fertilizer application, imposing a quadratic fertilizer response function to ensure a zero marginal return to nitrogen fertilizer use at a certain fertilizer quantity[8]. The econometric specification of the yield response function has the following form:

$$Y_{ih} = \alpha N_{ih} + \beta N_{ih}{}^2 + \gamma V_i + \delta W_j + X_r + \varepsilon_{ih} \text{ for } i = \text{plot ID}, h = \text{farmer ID}, \text{ and } r = \text{region}$$

where Y_{ih} is the crop yield on plot i from farmer h in kg; N_{ih} is the amount of nitrogen applied in kg, derived from the quantities of DAP and urea applied to the plot[9]; V_i is a set of plot-specific characteristics including soil quality (low, medium, high), plot area and its square; W_j is a set of farmer-specific characteristics, including household size and two location-related variables specifying the agro-ecological zone and annual precipitation that are linked to the farm's geo-location; X_r is a set of regional dummy variables; and ε_{ih} is the error term.

For each of the crop categories, the estimated coefficients α and β are assumed to represent the average fertilizer response function at the national level. However, these coefficients cannot be used for farms located in different agro-economic zones as each zone has different soil types, requiring different types of nutrients to maintain soil fertility. This also implies that the right type and quantity of fertilizer must be applied to different soil types in order to maintain or increase yield and profitability. Therefore, in the second stage we estimate the agro-economic zone-specific α and β to take into account, to a certain extent, the regional soil type which affects yield responsiveness to fertilizer application. These are derived by linking the coefficients of the national fertilizer response function to the profitability index for each agro-economic zone, per crop, as follows:

$$\alpha_z = \frac{TR_z}{TR} \times \alpha \quad \text{and} \quad \beta_z = \frac{TR_z}{TR} \times \beta,$$

where TR_z and TR indicate the average revenue per ha, in agro-ecological zone z and in the entire country, respectively, for the crop under consideration (whose identifier, for simplicity, is supressed). The resulting estimates of linear terms (α and α_z) and quadratic terms (β and β_z) of the corresponding fertilizer response functions are presented in Table 17.

Table 17: Linear and quadratic terms of the nitrogen response functions

Crop (seed type)	Linear term						Quadratic term					
	ETH	AgEc1	AgEc2	AgEc3	AgEc4	AgEc5	ETH	AgEc1	AgEc2	AgEc3	AgEc4	AgEc5
Teff (conventional)	8.781	10.007	8.342	7.901	8.603	8.343	-0.0507	-0.0578	-0.0482	-0.0456	-0.0497	-0.0482
Teff (improved)	9.500	10.826	9.025	8.548	9.307	9.026	-0.0550	-0.0627	-0.0522	-0.0495	-0.0539	-0.0523
Maize (conventional)	6.770	7.715	6.431	6.091	6.632	6.432	-0.0481	-0.0548	-0.0457	-0.0433	-0.0471	-0.0457
Maize (improved)	8.160	9.299	7.752	7.342	7.994	7.753	-0.0312	-0.0356	-0.0296	-0.0281	-0.0306	-0.0296
Wheat (conventional)	9.781	11.146	9.292	8.800	9.582	9.293	-0.0747	-0.0851	-0.0710	-0.0672	-0.0732	-0.0710
Wheat (improved)	10.500	11.966	9.975	9.447	10.287	9.976	-0.0800	-0.0912	-0.0760	-0.0720	-0.0784	-0.0760
Sorghum	9.239	10.529	8.777	8.313	9.051	8.778	-0.0552	-0.0629	-0.0524	-0.0496	-0.0540	-0.0524
Barley	6.130	6.986	5.823	5.515	6.005	5.824	-0.0376	-0.0428	-0.0357	-0.0338	-0.0368	-0.0357
Millet	9.239	10.529	8.777	8.313	9.051	8.778	-0.0552	-0.0629	-0.0524	-0.0496	-0.0540	-0.0524
Other cereals	6.130	6.986	5.823	5.515	6.005	5.824	-0.0376	-0.0428	-0.0357	-0.0338	-0.0368	-0.0357
Pulses	4.202	4.788	3.991	3.780	4.116	3.992	-0.0116	-0.0132	-0.0110	-0.0104	-0.0113	-0.0110
Oilseeds	6.130	6.986	5.823	5.515	6.005	5.824	-0.0376	-0.0428	-0.0357	-0.0338	-0.0368	-0.0357
Potatoes	10.761	12.263	10.223	9.682	10.542	10.224	-0.0456	-0.0520	-0.0433	-0.0410	-0.0447	-0.0433
Onion	10.761	12.263	10.223	9.682	10.542	10.224	-0.0456	-0.0520	-0.0433	-0.0410	-0.0447	-0.0433
Chat	1.688	1.924	1.604	1.519	1.654	1.604	-0.1390	-0.1584	-0.1320	-0.1251	-0.1362	-0.1321
Other spices	15.997	18.230	15.197	14.393	15.672	15.199	-0.1182	-0.1347	-0.1123	-0.1064	-0.1158	-0.1123
Other vegetables	10.761	12.263	10.223	9.682	10.542	10.224	-0.0456	-0.0520	-0.0433	-0.0410	-0.0447	-0.0433

NB: Whenever improved seed is used, the seed type is indicated after the crop name within brackets. Where only conventional seed is used, the seed type is not indicated. ETH refers to Ethiopia. The five agro-ecological zones are: AgEc1: Amahara, Benshangul-Gumuz; AgEc2: Oromia, Gambela, Harari, Diredawa; AgEc3: SNNP; AgEc4: Somali, Afar; and AgEc5: Tigray. The coefficients for Pulses apply separately to chickpeas, horse beans, haricot beans, field peas, lentils, and other pulses. Similarly, the reported coefficients for Oilseeds are the same for nuegs, linseeds, and other oilseeds.

[8] Here, plots with no fertilizer application were excluded.

[9] For plots with mixed cropping, we assume that fertilizer has been distributed homogeneously over the entire plot, such that the amount of fertilizer applied to each of the crops is proportional to the crops' reported share in plot area.

To assess the reasonability of the estimates of fertilizer response functions in Table 17, we compute the marginal yield response of each crop to fertilizer use, $\partial Y/\partial N = \alpha + 2\beta N$, evaluated at the sample means of nitrogen use for each crop and seed type. The results are shown in Table 18. The table does not report the corresponding figure for cases of zero nitrogen use. For example, the reported figure of 4.71 for maize (improved seed) in the entire country implies that one extra unit of nitrogen (or marginal unit) applied by farmers using improved seed yields 4.71 kg of maize, on average, throughout Ethiopia. The corresponding maize marginal yield response in Amhara, Oromia, SNNP and Tigray are 4.86, 4.77, 4.55 and 2.25, respectively. The corresponding maize marginal yield response for plots where conventional seed is used are smaller in Amhara, Oromia and SNNP by, respectively, 52%, 31% and 21%, but a little larger in Tigray (8%). There are only a few cases when marginal yield response is smaller with improved seeds than with conventional seeds, which is basically driven by large differences in their corresponding average use of nitrogen. For example, for the latter case of Tigray, average nitrogen use by our sample farmers growing maize with conventional and improved seeds are, respectively, 43.9 kg/ha and 92.9 kg/ha. Since farmers using improved seeds already apply large amounts of fertilizer compared to farmers using traditional seeds, it is not surprising to find smaller marginal yields for the improved seeds case. Throughout the country, on average, the marginal maize yield response to fertilizer use is 53% higher for farmers using improved seeds compared to those using conventional seeds (4.71 vs 3.07). Here, the sample average nitrogen use, throughout Ethiopia, is 38.4 kg/ha for growing maize with conventional seed, and 55.3 kg/ha for improved seed. Note that the average nitrogen intensities for all seed types were already reported in Table 11.

Table 18: Estimated marginal yield response to fertilizer use

Crop (seed type)	ETH	AgEc1 (Amhara)	AgEc2 (Oromia)	AgEc3 (SNNP)	AgEc4	AgEc5: Tigray
Teff (conventional)	5.64	6.63	5.16	5.01		5.53
Teff (improved)	5.78	7.00	5.37	4.49		6.09
Maize (conventional)	3.07	2.31	3.31	3.59	5.84	2.42
Maize (improved)	4.71	4.86	4.77	4.55		2.25
Wheat (conventional)	3.28	3.09	3.25	3.37		3.07
Wheat (improved)	3.28	3.39	4.08	3.39		2.72
Sorghum	6.26	7.41	5.91	5.30	7.72	6.07
Barley	3.48	4.60	3.44	2.72		3.12
Millet	6.70	7.78	7.63	5.97		5.69
Chickpeas	3.72	4.24	3.56			3.49
Horse beans	3.53	4.05	3.39	3.24		3.07
Haricot beans	3.54	3.48	3.32	3.26		3.70
Field peas	3.57	4.37	3.20	3.19		3.17
Lentils	3.32	4.22	3.03	3.28		3.11
Other pulses	3.55	4.03	3.29			3.76
Nuegs	3.46	4.64				3.29
Linseeds	4.08	4.44	4.23			2.85
Other oilseeds	2.99	2.84	3.63			
Potatoes	6.24	7.75	5.49	5.43		5.70
Onion	6.73	6.85	7.02	9.08		
Other spices	2.74	2.47	5.09	1.44		
Other vegetables	6.27	6.78	6.17	6.02		4.24
Min	2.74	2.31	3.03	1.44	5.84	2.25
Max	6.73	7.78	7.63	9.08	7.72	6.09
Average cereals	6.70	7.78	7.63	5.97	7.72	6.09
Average all crops	4.36	4.87	4.49	4.31	6.78	3.86

NB: Yield responses represent marginal product estimated from the quadratic crop yield to fertilizer use response function, evaluated at the respective sample mean of nitrogen use. For zero nitrogen use, the corresponding figures are not reported. For abbreviations, see the note to the previous table. For the full list of the five agro-ecological zones, see note to Table 17.

Rashid et al. (2013, Table 9) report estimated marginal yield response for the main cereals in Ethiopia, for fertilizer users only, as follows:

1. Maize: 3.75 (Ethiopia), 3.78 (Amhara), 4.49 (Oromia), 3.76 (SNNP), 4.15 (Tigray).
2. Teff: 1.73 (Ethiopia), 1.79 (Amhara), 2.00 (Oromia), 1.92 (SNNP), 1.96 (Tigray).
3. Wheat: 2.05 (Ethiopia), 2.20 (Amhara), 2.24 (Oromia), 2.25 (SNNP), 2.50 (Tigray).

Comparing our results from Table 18 to those estimated in Rashid et al. (2013), we find the two estimates of marginal yield response are comparable in the case of maize. However, our estimates are higher for wheat and especially for teff: our marginal yields, averaged over seed types, are higher than the corresponding estimates reported in Rashid et al. (2013), on average by 47% for wheat and 203% for teff. All the differences would be (much) smaller if we had chosen Rashid et al.'s marginal yield estimates for all households, irrespective of use or non-use of fertilizer. In general, all these differences can be, at least partly, explained by the fact that the underlying data are different. Rashid et al. (2013) use EDRI-IFPRI household survey for 2008, while our estimates are based on ESS survey data for 2013/14. Thus, it could be the case that over time (from 2008 to 2014), yield response and profitability in Ethiopia has improved due to, for example, the use of improved agronomic practices, including better fertilizer application and soil management practices[10].

Finally, the shift parameter (intercept) of the fertilizer response function is farm- and crop-specific. It is obtained during the calibration step for the observed crop yields within the FSSIM-Dev model. The underlying mechanism of this calibration step is the maximization of profit per unit of area, where the quantity of fertilizer use and the intercept of the fertilizer response function are endogenous variables, while the linear and quadratic terms of the response function are exogenously given, as presented in Table 17 (more details are provided in Louhichi et al., 2019).

[10] It must be noted that the prices of crops have increased since 2013/14, which directly affects the profitability of farmers. In the same vein, other relevant for our modelling purposes farm-level data (presented in this section) have experienced notable changes over time. Hence, the results presented in this report may not represent well the current situation and, certainly, the use of more recent data (e.g. of 2018/19) would have been much better. However, such data is currently unavailable.

5 The ACC initiative: overview and policy scenarios

5.1 Policy background

The main basis for the Growth and Transformation Plan II (GTP II, 2015-2020) is Ethiopia's vision of becoming a lower middle-income country by 2025. Since agriculture still plays a critical role in the country's economic, political and social development (according to the World Bank's World Development Indicators, in 2017 agriculture accounted for 34% of Ethiopia's GDP and generated 66.2% of its total employment), it is recognised that 'in GTP II period, agriculture will remain the *main driver* of the rapid and inclusive economic growth and development … [and] *main source of growth* for the modern productive sectors' (National Planning Commission, 2016, Volume I, p. 78, italics added). Furthermore, given that crop production makes up 72% of total agricultural GDP, while over 90% of farmers are smallholders cultivating one hectare or less of land (Cheru et al., 2019), the important focus of the transformation agenda is increasing production and productivity of crops cultivated by smallholder farmers and shifting their subsistence-based production towards market-based production. This development strategy is expected to significantly improve food security and incomes of Ethiopian smallholder farming families, accelerating rapid and inclusive growth of agriculture, and thus considered to make an important contribution to reaching the objectives of GTP II[11].

The Agricultural Transformation Agenda, which is principally owned by the Ministry of Agriculture and its affiliate institutions, was introduced in 2013 during the first GTP (GTP I, 2010-2015) to address the systemic bottlenecks in the agricultural sector. However, the scope and orientation of the Transformation Agenda was expanded in GTP II, and 'overall, the focus has shifted from an emphasis on solely increasing production and productivity to enhancing the downstream or market components of crop and livestock value chains' (ATA, 2019)[12]. In addition, the Agricultural Commercialization Cluster (ACC) Initiative was introduced during GTP I as a mechanism to integrate the Transformation Agenda interventions along specific value chains for a limited number of priority (or high-value) commodities in high-potential areas (known as geographic clusters or economic corridors) across the country. This geographically focused approach is, in essence, modelled on successful experiences implemented by Asian, Latin American and African countries in the process of their agricultural transformation and rural industrialization (Gálvez-Nogales, 2010). The ACC initiative is owned and implemented mainly by regional governments and the Regional Bureaus of Agriculture.

5.2 Overview of the ACC initiative

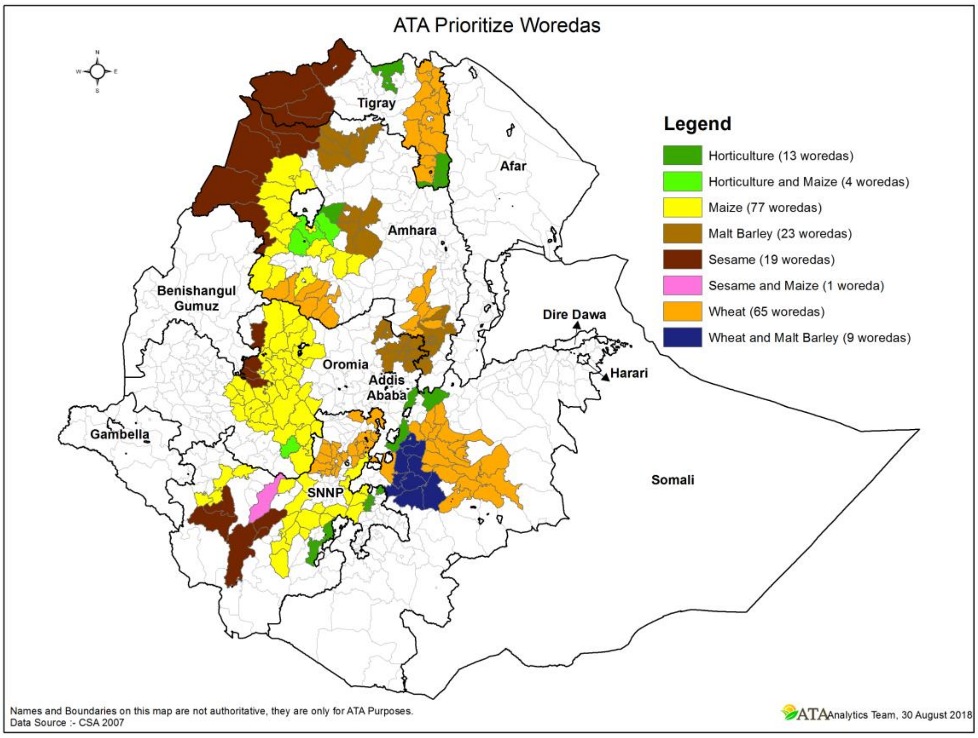
The ACC contains 24 geographic clusters, spanning 252 *woredas* across the four major agricultural regions of Ethiopia: Amhara, Oromia, SNNP and Tigray (see Figure 19). These clusters are considered to play the role of Centres of Excellence, and are being supported in expanding their production and productivity, and in integrating their commercialization activities. Therefore, these areas are meant to serve as 'models for learning' in the process of implementation of the ACC approach and scaling up best practices across the country. In particular, in these clusters the ACC initiative targets 10 prioritized commodities: wheat, maize, sesame, malt barley, teff, tomato, onion, banana, mango, and avocado[13].

[11] It is claimed that agriculture is already making a major contribution towards this end: the proportion of population living below the poverty line dropped from 39% in 2006/2007 to 22% in 2016/2017, and over this period food security and incomes of nearly 12 million smallholder families have improved (ATA, 2019).

[12] For details on the Transformation Agenda's priority interventions (called deliverables) and key workstreams (called subdeliverables) across four thematic pillars of Crop and Livestock Production & Productivity, Agri-business & Markets, Environmentally Sustainable & Inclusive Growth, and Enhanced Implementation Capacity, and cross-cutting issues (Climate Change Adaptation & Mitigation, Gender, Nutrition, Targeted Livelihood Support and Biodiversity) see e.g. ATA (2017).

[13] Earlier, the list included 12 prioritized commodities: besides the 10 mentioned, ATA (2017) also included haricot beans and apiculture output (honey and wax).

Figure 19: The ACC prioritized woredas in 2018 and 2019



Source: Ethiopian Agricultural Transformation Agency website, www.ata.gov.et

Based on agro-ecological and market conditions in the specific areas, in each cluster one of the 10 prioritized commodities is considered as the primary crop. However, for the purposes of environmental sustainability and minimization of mono-cropping patterns, secondary and rotational crops are also identified. To better understand the exact nature of interventions conducted in the ACC cluster areas, which will define our subsequent policy simulations, in Table 19 we summarize the major actions undertaken by the ACC initiative in each region and cropping season. A closer look into these actions reveals that the ACC strategy has a rather wide scope of undertaking, operating from the coordination and decision-making stage at the higher levels of regional governments, Regional Transformation Councils (RTCs), the Ethiopian Agricultural Transformation Agency (ATA) and other stakeholders, down to the stage of direct involvement and incentivizing of farmers, and further down to the stage of establishing and coordinating market linkage. Nonetheless, one could single out the most important success factors for the ACC clusters, at the level of implementation by smallholder farmers, as follows:

- easier access to input financing (e.g. through scaling the Input Voucher Sales system);
- better and timely distribution of (improved) seed, fertilizer and agro-chemicals (e.g. with the help of seed-producing and marketing unions);
- trainings and large-scale demonstrations provided to farmers on their fields or at Farmer Training Centres (FTCs) on improved or new farming technologies, crop management techniques, crop protection, soil fertility and health, agronomy, and contract farming;
- farmers' field days on priority products, especially when carried out at each stage of production (e.g. planting, vegetating, and fertilizer and agrochemical application);
- contract farming agreements made between producers and buyers (e.g. primary cooperatives, farmers' cooperative unions, agro-processors).

All in all, one can state that the ACC interventions have the features of 'Green Revolution technology' which is not only 'seed-fertilizer intensive' but also 'management-intensive' (e.g. Otsuka and Larson, 2016; Larson et al., 2016; Otsuka and Muraoka, 2017). The latter characteristic refers to the adoption of improved or best agronomic practices (e.g. land preparation, row planting, fertilizer and/or improved seed applications) for the crop under consideration, including soil management practices[14]. For example, the application of organic fertilizers such as manure, compost and crop residues maintains or improves soil organic matter content, which is a key component of soil fertility, and thus also increases yield response to inorganic fertilizer (see e.g. Marenya and Barrett, 2009; Morris et al., 2007; Kajisa and Palanichamy, 2013).

It is clear that these important management-related ingredients of an agricultural policy aiming to increase crop production and productivity within the ACC framework are captured by farmers' participation in extensive trainings, large-scale plot demonstrations and field days. There is abundant literature confirming that often training programmes in the best agronomic practices, or simply applying the best management practices, lead to (significantly) higher yields compared to the performance of non-trained farmers or farmers not applying improved agronomic practices (see e.g. Romani, 2003; Anderson and Feder, 2007; Vandercasteelen et al., 2013; Alemu et al., 2014, Waddington et al., 2014; Gollin et al., 2015; Otsuka and Larson, 2016; Hailu et al., 2016; Mann and Warner, 2017; Nakano et al., 2018; Takahashi et al., 2018).

In the case of Ethiopia, Davis et al. (2010) carried out an in-depth assessment of the public agricultural extension system in the country and recommended, in particular, focusing on: (i) strengthening the skills and knowledge of development agents (DAs) and subject matter specialists (SMS) in FTCs and *woredas,* as their ability to serve farmers was found to be limited due to a lack of practical skills; (ii) resourcing the FTCs in terms of buildings and demonstration plots, and operating capacity of the FTCs to conduct farmers' demonstrations; (iii) farmer-driven orientation across all levels of extension services, which focuses on farmer needs at the *woreda* and *kebele* levels; and (iv) improving linkages throughout the extension system, e.g. between research and extension centres, so that farmers can receive critical information and support in a timely manner, while research efforts are tied to farmer needs. Apparently, these recommendations are taken on board in the ACC initiative, where there is critical emphasis on raising farmers' awareness of improved input varieties and fertilizer use, providing farmers with extensive trainings and large-scale plot demonstrations, and conducting field days.

It is also implicitly recognized that even a one-time policy intervention (e.g. extension service) can change farming behaviour permanently, provided that the intervention imparts relevant knowledge about input use and farming techniques that result in higher productivity and profitability (e.g. Matsumoto et al., 2013).

One of the factors in maintaining consistent high cereal yields is utilizing certain components of the precision agriculture approach, e.g. when precision management is applied uniformly to the entire field through exact timing and placement of specific field operation, or when site-specific management within a field is conducted that explicitly accounts for variation in location-specific crop resource requirements, soil properties, pests and disease (Cassman, 1999). Theory suggests that site-specific management increases fertilizer efficiency and reduces nitrate leaching (Pierce and Sadler, 1997). Therefore, the ACC initiative - by focusing on specific geographic locations and providing site-specific (e.g. fertilizer) recommendations to farmers - is also, in effect, trying to reap the potential benefits expected from the application of a site-specific management approach.

[14] The specific crop-productivity supporting soil properties, such as nutrient reserves, water-holding capacity and favourable structure for root growth, are directly related to the physical attributes of soil (e.g. size and continuity of pores, impedance, texture, aggregate stability), its chemical proprieties (e.g. nutrient stocks and availability, organic matter content and composition, mineralogy), and biological attributes (e.g. quantity, activity and diversity of microbial biomass and soil fauna). For details, see e.g. Cassman (1999).

Table 19: Major actions undertaken by the ACC initiative

2016/2017 planting season	2017/2018 planting season
Amhara	
– Input financing through scaling (strengthening) of the Input Voucher Sales (IVS) system – Improved fertilizer distribution mechanisms (e.g. network of unions used to transfer fertilizer to farmers in case of delay in fertilizer supply) – Successfully identified the quantity of seed varieties demanded – Site-specific fertilizer recommendations given – 14 Large-Scale Plot Demonstrations (LSPDs) carried out – Farmers engaged in 711 field days, reaching 32,419 participants – Established Value Chain Alliances (VCAs) strengthened relationships between stakeholders (e.g. workshops engaging 1,331 stakeholders held to discuss input and credit supply, production and marketing performance) – Strong market linkages on producing crops, aggregating and storage. Large share of cereals (84%), pulses and oilseeds purchased by unions through contractual agreements. – Regional Transformation Council (RTC) identified domestic and international markets for cluster commodities, and established market steering and technical committees.	– ATA and RTC provided multi-stakeholder coordination and decisions on timely input distribution, cooperative support for input and output finance, prioritization of interventions, commodity-specific support (incl. price stabilization), and focus on immediate actions (e.g. fighting fall armyworm infestation) – 51,451 quintals (qt) of seed, 1,251,706 qt of fertilizer and 133,502 qt of agrochemicals were distributed – Training on crop production enhancement technology packages and implementation approaches provided to 809,223 smallholder farmers, 4,799 development agents (DAs), and 1,039 subject matter specialists – 7 regional field days on priority products conducted – Market linkage forums and contract farming training conducted, to enable farmer organizations to aggregate produce and deliver to markets in timely manner and at competitive prices – Contract farming agreements made between producers and buyers for 173,000 qt of bread wheat, 55,500 qt of sesame – 16 VCA workshops conducted, to identify major bottlenecks for each cluster commodity value chain and to propose solutions
Oromia	
– RTC focused on aligning all critical stakeholders on the value and priorities of the ACC initiative – Market linkages performed well – Pre-financed input credit arranged for malt barley farmers by agro-processors, providing input credit amounting to ETB 36 million – Timely seed and fertilizer distribution; Direct Seed Marketing modality utilized for the distribution of maize seed – Contract farming agreements signed between 9 farmer cooperative unions, 67 primary cooperatives, 5 agro-processors, 2 colleges, and 3 commercial farms	– The ACC initiative facilitated provision of 198,710 qt of improved seed, 1,485,548 qt of fertilizer, and 477,857 litres of agro-chemicals – Training in improved farming techniques provided to 2,573 DAs, 434 experts, and 1,266,355 smallholder farmers – All planned VCA meetings conducted, implementation action plan developed – Contract farming agreements made to facilitate market linkage between producers and cooperatives for a total of 4.4 million qt of priority commodities (of which 2 million qt were already sold as of the day of publication of ATA (2019))
Southern Nations, Nationalities, and Peoples (SNNP)	
– RTC recommended capacitating input suppliers and linking smallholders with crop insurance to mitigate the risk of mono-cropping – 3 VCA meetings conducted, particularly effective at creating common understanding among stakeholders (3 new stakeholders introduced) – Increase in demand and supply of improved seeds, due to establishment of 3 seed-producing and marketing unions, support to existing seed producing unions,	– Trainings on a series of topics provided to 3,410 zonal, *woreda* and *kebele* experts, facilitating training for 602,616 farmers – 1,832 large-scale demonstrations on new technologies and crop management techniques conducted on farmers' fields and at farmer training centres – Farmers' field days carried out at *woreda* level at each stage of production: planting, vegetating, and fertilizer and agrochemical application

and facilitation of access to input credit – Wheat rust prevention agro-chemicals distributed to cover 30% of cultivated land – Farmers' awareness raised, on improved seed varieties demanded on export markets and creating market linkages with international buyers – LSPDs achieved 99% of target – Trainings on agronomy, crop protection, soil fertility and health, market-oriented extension and contract farming provided to 725 *woreda* experts, 2,755 DAs and 602,616 farmers. – Contract agreements signed between 11 farmers' cooperative unions (FCUs) and 8 buyers (though mutual failures to adhere to the agreements were observed) – Well-equipped storage facilities under construction, primary cooperative and FCU staff provided with training – ACC supported two cooperative unions (Sidame Elto and Damota Wolaita) to enter the haricot bean export market	– RTC emphasized review of work done and need to strengthen coordination and integration among various stakeholders (incl. integration with other ATA-led initiatives) – VCAs for each commodity clarified roles and responsibilities of each actor, created market linkages and contract agreement platforms, and evaluated clusters' input utilization plans and performance – VCAs created a viable contract farming modality to inform farmers of the quality requirements of buyers and processors – Contractual agreements made between 7 buyers' and 10 producers' unions for 225,000 qt of wheat, 155,000 qt of haricot bean – Regional government provided agro-chemicals to fight the outbreak of fall armyworm – Regional government made credit access available to farmers for input and output marketing, supported field supervision and capacity building to improve the functions of FCUs on grain marketing
Tigray	
– Based on three surveys and assessments, RTC decided that linkages between mechanization suppliers and FCUs should be strengthened and the IVS system be scaled up throughout the region; Tigray Agricultural Marketing Promotion Agency directed to work on market linkages for contract farming arrangements – Trainings to support Integrated Delivery Scale-up (IDS) initiative provided in 207 *kebeles*, reaching 99% of targeted subject matter experts, 98% of DAs and 90% of farmers; farmers' trainings engaged all members of the farming households – 208,082 qt of fertilizer, 61,024 qt of improved seed, and 28,331 litres of agro-chemicals distributed in teff, wheat and sesame cluster *woredas* – VCA meetings conducted to identify and solve challenges encountered in contract farming agreements (e.g. subsidies on imported wheat drive down price and discourage processors from buying from local farmers)	– 2 RTC meetings conducted on timely input distribution, support to cooperatives on input and output finance, and other commodity-specific support – ETB 15 million in output financing made available to cooperatives, action plan developed to fight fall armyworm, guidelines developed for effective assessment of input demand – Contract farming agreements made for 139,345 qt of the various commodities combined - although only 30% of agreed amount, valued at ETB 72,87 million, sold (due to farmers' refusal to supply their crops through the contract farming agreements, as the prices were lower than their expectations, and thus farmers stored their harvest waiting for higher prices)

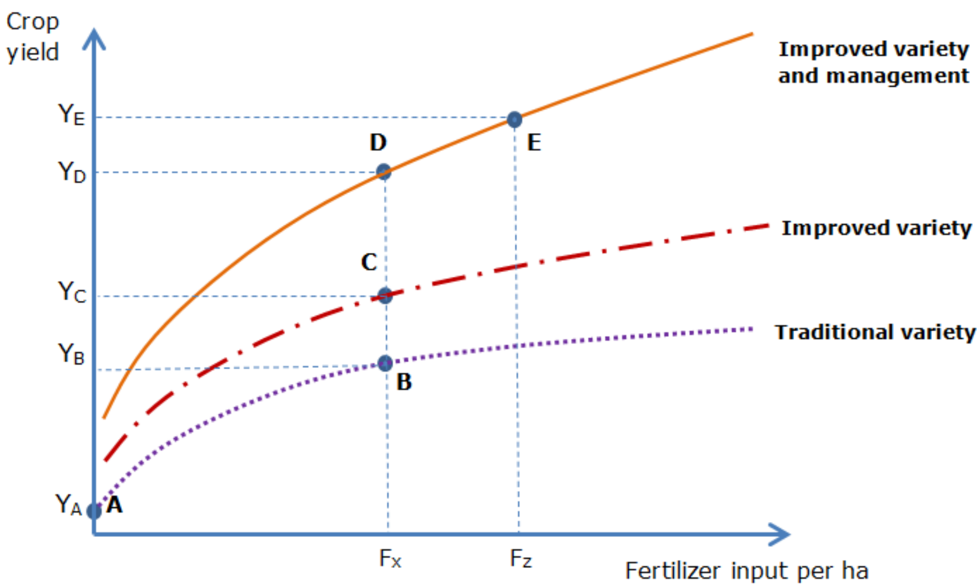
NB: All information summarized in this table was extracted from ATA (2017, 2019) annual reports.

5.3 Formalizing the ACC initiative impacts

To formalize and assess the potential impacts of the ACC initiative discussed in section 5.2, it is useful to figure out how these changes in technology and in farming practices may affect the crop yield response to fertilizer application function. In particular, let us discuss the yield impact of the following theoretical effects: (i) effect of technology (e.g. use of improved seeds); (ii) combined effect of technology plus improved management practices; and (iii) combined effects of technology plus improved management plus lower input prices/costs and/or higher/stable output prices.

Point A in Figure 20 illustrates the case where a farmer uses a traditional seed variety without any chemical fertilizer application. With the use of fertilizer, however, crop yield increases as we move upward along the 'Traditional variety' fertilizer response function: i.e. yield increases from Y_A without fertilizer use to Y_B when F_X kg/ha of fertilizer has been applied to the cultivated area. For simplicity and without loss of generality, the (theoretically possible) downward-sloping part of this curve is not shown - where fertilizer overuse damages salinity and creates specific nutrient toxicities that negatively impact crop yield. As fertilizer application increases, incremental yield gains along the fertilizer response function get smaller, because yield determinants other than fertilizer become more limiting (which is the general explanation of the law of diminishing returns).

Figure 20: Fertilizer response function: the effects of technology (e.g. new varieties), improved management practices, and reduced fertilizer costs or increased output prices



Crop yield response (to fertilizer use) functions can shift up or down for many reasons, such as technological, environmental and economic factors (Dawe and Dobermann, 1999). An example of a technological factor is the introduction of new varieties with better adaptation to abiotic or biotic stresses (e.g. pests, diseases, weeds, lodging), which will shift the fertilizer response function up, as illustrated by the 'Improved variety' response function in Figure 20. Using improved varieties results in higher yield Y_C for the same level of fertilizer input F_X kg/ha. On the other hand, factors such as a decline in the indigenous nutrient-supplying capacity of soil, insufficient water supply, a decline in the uptake capacity of the root system due to soil toxicities or pathogens, deficiencies of other nutrients, and yield losses from insects, disease and weeds would shift the response function down (Dawe and Dobermann, 1999; Cassman et al., 2003; Otsuka, 2016).

Further increase in (potential) yield from Y_C to Y_D is feasible if the use of improved varieties is combined with the adoption of improved (or best) management practices, as illustrated by the 'Improved variety and management' response function in Figure 20 (Otsuka, 2016; ACET, 2017). In addition to our earlier discussions on improved management practices, another example of improved management is the optimal timing of fertilizer applications.

Note that in Figure 20, we have assumed that the policy interventions generally described above also positively affect the marginal product of fertilizer; thus the fertilizer response functions shift upward, both in their level and curvature (higher slope). That is, focusing on management practices, it is assumed that yield responsiveness to fertilizer increases with adoption of best agronomic practices, for any given level of fertilizer application. In practice, however, it is not so straightforward to make an *ex ante* exact prediction of how the coefficients of the response function would change: e.g. management practices that encourage enhancement of soil quality, depending on the nature of the practice adopted and soil type, affect the (interdependent) physical and chemical properties of soil that influence its water-holding capacity, root development, water infiltration rate, availability of phosphorus and sulphur, etc., and these ultimately determine crop yield (Cassman, 1999; Cassman et al., 2003).

It is widely accepted that adoption and diffusion of modern agricultural technologies is one of the key pathways for agricultural transformation and economic growth in developing countries (Evenson and Gollin, 2003; Gollin, 2010). A large body of literature explaining limiting factors for technology adoption in sub-Saharan Africa points to such issues as credit constraints, high transaction costs and other market imperfections. In the case of Ethiopia, it is supply-related constraints that are commonly found to explain the low levels of adoption of improved seed and chemical fertilizers (Croppenstedt et al., 2003; Morris et al., 2007; Dercon et al., 2009; Davis et al., 2010; Spielman et al., 2011)[15]. In particular, the literature emphasizes such factors as late delivery of inputs (e.g. seeds and/or fertilizer arriving after optimal planting time), delivery of seeds not appropriate to farmers' expectations based on e.g. changing seasonal weather conditions, shortcomings in seed or fertilizer quality (e.g. poor seed cleaning, broken seeds, low germination rates, presence of mixed seeds, underweight bags of fertilizer), limited access to credit, and high procurement, marketing and distribution costs for inputs. Looking into the actions taken under the ACC initiative (Table 19), it is clear that one of the main aims of the initiative is to deal with these long-standing problems, particularly through facilitating access to input financing, and timely and improved distribution of seeds, fertilizer and agro-chemicals. Removing such supply constraints is a cost-reducing policy that is expected to raise adoption rates of improved seeds and fertilizer, which should also result in increased crop yields (Suri, 2011; Zeng et al., 2015). In terms of the fertilizer response function in Figure 20, a decrease in explicit or implicit cost of fertilizer (e.g. due to timely delivery of a better quality fertilizer) implies an upward movement along the existing function, leading to larger amounts of fertilizer application. Thus, if in addition to adoption of improved seeds and best agronomic practices, the explicit and/or implicit costs of fertilizer go down, higher quantity of fertilizer F_Z kg/ha is used by the farmer, which would lead to a further increase in crop yield from Y_D to Y_E kg/ha.

Increase and/or stabilization in output prices have exactly the same (theoretical and graphical) effect on fertilizer use and crop yield as reduced fertilizer costs. Higher output prices imply higher marginal product value for fertilizer use, hence a rational farmer will apply a larger quantity of fertilizer per ha of cultivated land. In the same vein, less volatile (more stable) output prices imply less uncertainty over farmers' future revenue-generating capability when marketing their production. Therefore, more confidence and good expectations on realization of future revenues lead farmers to use more inputs, including chemical fertilizer. In the latter case, more stable output prices could be interpreted as lower implicit costs of fertilizer. Graphically, this is again represented by an upward movement along the existing fertilizer response function, resulting in higher yield. It should however be noted that an increased use of inputs other than fertilizer (such as using more seeds and agro-chemicals, or higher availability of labour) would cause an upward shift in the fertilizer response function.

The final component that is also given a critical role in the ACC initiative, as follows from Table 19, is contract farming (CF) arranged between farmers and buyers (primary cooperatives, farmer cooperative unions, agro-processors, commercial farms, etc.). CF is often considered to serve as a device for agricultural modernization and poverty reduction through introduction of new technologies, new high-value crops, and improved marketing systems (World Bank, 2007). Some of the principal reasons for an increased interest in CF agreements are that these arrangements help to solve market failures due to asymmetric information about food quality and safety, reducing transaction costs and risk, and providing farmers with ready markets with increased ultimate returns, new technologies, and secured inputs and prices (Kirsten and Sartorious, 2002; Barrett et al., 2012; Otsuka et al., 2016). In general, there are two other alternatives to CF arrangements: spot-market transactions (where agricultural commodities are traded directly in spot markets) and vertical integration (where production, processing and marketing activities are fully integrated). The choice between

[15] Recently, Abay et al. (2017) and Taffesse and Tadesse (2017) found that behavioural and psychological attributes (namely, internal vs external locus of control) of farmers in Ethiopia do also explain the low rates of adoption of profitable agricultural technologies. This implies that improving farmers' non-cognitive skills may facilitate agricultural transformation. One 'avenue to consider is bundling the standard (technical) extension services with "interventions" aimed at boosting locus of control and other psycho-social characteristics (such as aspirations)' (Abay et al., 2017, p. i55).

these three alternatives generally depends on the degree of information friction, relative efficiency of production, extent of market competitiveness, prevailing quality and safety standards, and product characteristics (Key and Runsten, 1999). There are transaction costs involved with CF arrangements, including costs of searching for and identifying skilful farmers, negotiating and enforcing contracts, and controlling implementation of the agreed conditions regarding product quality, safety, volume, delivery timing, use of inputs, and price or pricing formula (Glover, 1987; Wang et al., 2014). In this respect, the role of the ACC initiative is helping smallholder farmers and potential buyers to deal with these transaction costs and to facilitate the resulting market linkages, using its capacity building and networking potential, including through establishing Value Chain Alliances that involve all interested stakeholders in the process.

Formalizing the impact of CF arrangements within our farm household modelling framework also results in an upward movement along the existing fertilizer response function (when the CF leads to reduced fertilizer costs due to e.g. delivery of fertilizer at lower costs and/or agreed higher or certain/less volatile output prices in the future) and/or upward shift in the fertilizer response function (when the contract e.g. brings in improved production methods and new technology and/or reduces the costs of other inputs). In their literature review of CF in developing and developed countries, Osuka et al. (2016) 'conclude that CF contributes to the improvement of productivity in farming' (p. 369). They stress that some of the mechanisms through which CF increases productivity are the transfer of improved production and marketing methods to farmers, and mitigation of market failures. Indeed, in the case of Ethiopia, in 2013 the ATA introduced the Wheat Initiative, designed to expand smallholders' productivity. To simultaneously address multiple constraints faced by farmers, the Wheat Initiative promotes the use of a package consisting of improved inputs (certified wheat seed, urea, DAP and gypsum), improved farming techniques (lower seeding rates, row planting and balanced fertilizer use), and a guaranteed market for output (before the planting season, the government commits to buying farmers' wheat at or above the market price to reduce marketing risk for smallholders). Abate et al. (2018) evaluated the impact of the Wheat Initiative on yields among a promotional group of farmers - those who received training on agronomic practices, certified wheat seed on credit, urea fertilizer, gypsum (as an in-kind per diem for taking part in the training), and marketing assistance after harvest - vs a treatment group receiving only marketing assistance. They found that the full package led to an average 14% higher yield, while the marketing guarantee alone did not affect yields.

Our discussions, particularly in section 5.2 and above in this section, reveal that the ACC initiative is basically about expanding the quantity and quality of three interrelated agricultural inputs (chemical fertilizer, improved seeds, and extension and advisory services), and facilitating market linkages on the output side of smallholder farming 'business'. Thus, similar to the Wheat Initiative package, the goal of the ACC is relaxing multiple (or arguably the most relevant) constraints on agricultural productivity, as outcomes are expected to remain suboptimal if only one or a few constraints are relaxed while farmers still face other critical constraints (Foster and Rosenzweig, 2010). In this respect, it is important to mention that providing input packages is meant to exploit the potential complementarities between two or more modern inputs, and to facilitate farmers to adopt technologies simultaneously rather than sequentially. Two inputs (technologies) are defined to be complementary if the marginal return for one input (technology) increases with additional use of the other (Milgrom and Roberts, 1995). For example, most improved seeds are believed to provide high yield only when jointly used with chemical fertilizers (Ellis, 1992; Abay et al., 2018).

The literature on the impact of extension services on adoption of technology is in general mixed. In the case of Ethiopia, Ragasa et al. (2013) and Abay et al. (2018) found that extension services are positively associated with the adoption of improved seeds and fertilizer. On the other hand, Krishnan and Patnam (2014) found a strong initial impact of extension services on adoption of fertilizer and improved seeds, which however disappears after some time, in contrast to the corresponding effect of learning from neighbours. Yet Bueheren et al. (2017) find no evidence of the impact of extension services on fertilizer adoption, but a positive impact on the number of household members contributing to income, on land area cultivated, and on farming and selling of marketable crops. These last findings suggest that extension services helped Ethiopian smallholder farmers to switch to more commercial, market-oriented agriculture[16].

[16] However, a note of caution is due here: the problem of endogeneity of extension services may result in biased estimates of the effectiveness of extension services on fertilizer and/or improved seed adoption that are reported in all the existing studies. In fact, Dercon et al. (2009) and Ragasa et al. (2013) indicate that it is even difficult to predict the direction of bias associated with the endogeneity of extension services. Abay et al. (2018) show that ignoring household-specific unobserved heterogeneity (e.g. differences in returns to specific technology adoption, households' preferences and risk-taking behaviour) and input complementarity leads to significant overestimation of the effectiveness of extension services in facilitating technology adoption.

5.4 Performance of the ACC initiative

Now that we have discussed in detail the exact nature of the ACC interventions in section 5.2, and formalized theoretical effects of these interventions in section 5.3, it is time to report on the outcomes obtained so far from this initiative. The performance of the ACC clusters during the 2016/2017 and 2017/2018 planting seasons, in terms of crop production (in quintals, qt), area of land cultivated (in hectares, ha) and the resulting land productivities or yields (qt/ha), were extracted from the annual reports of the Ethiopian Agricultural Transformation Agency (ATA) and are summarized in Table 20. Productivity differences between 'model farmers'[17] and 'non-model farmers' are obtained using only the reported cluster and regional productivities. That is, following ATA (2017), productivity gains for the ACC clusters were computed as the reported average yield of cluster *woredas* (by region) minus the corresponding reported regional yields. Arguably, these quantify approximate yield gains. We understand that different arguments could be raised both for and against such an approach, but this is the best one can do with the currently available data.

Unlike ATA (2017), unfortunately the (cluster and) regional average yields are not reported in ATA (2019) for the 2017/2018 cropping season. Therefore, to avoid making unrealistic assumptions (e.g. yearly variation in yields can be large due to changing weather conditions), the latter data was not used in calculating productivity differences between cluster and non-cluster *woredas*. Nonetheless, reported data on production and land cultivated for the 2017/2018 crop season, along with the implied computed yields, are also given in Table 20. These are useful for observing the dynamics of computed (not reported) yield changes for cluster *woredas*.

The underlined and italicized numbers in Table 20 indicate a reporting typo/error. There was apparently a typo made in reporting the production volume for bread wheat and teff in Tigray for the 2017/2018 planting season, as these are reported to be exactly the same and (much) lower than the previous planting season.

A second reporting error must have been made in reporting the production volume for malt barley in Amhara for the 2016/17 cropping season as 19,567 qt, since this would result in average productivity of roughly 9.72 qt/ha (= 19,567 qt / 2,013 ha), which is very low compared with the reported average productivity of 20.8 qt/ha (Table 20). Furthermore, for this particular case ATA (2017) reports marketable surplus amounting to 20,064 qt, which confirms that the reported production volume for barley is most probably understated. However, this does not have any implications for construction of our scenarios, as these are based on the reported (for 2016/17) average productivity, which seems realistic (and in line with the corresponding implied productivity for the next crop season).

We excluded the reported results for sesame planted in Amhara and Tigray, because these clusters showed productivity losses when compared with the corresponding regional average productivities. The resulting yield losses were -43.27% in Amhara, and -11.13% in Tigray, for the 2016/2017 crop season. As such poor performance would not fit the achievements to be expected from 'model farmers' to be scaled up across the country, we have decided to exclude sesame from our impact assessment exercises. However, the challenges faced by the ACC farmers that are discussed in the report explain the poor performance of sesame growers. For example, in the case of Amhara in the 2016/2017 cropping season, ATA (2017) raises concerns about the 'limited amounts of improved seed for sesame; poor uptake of improved inputs and practices (especially on sesame)' (p. 34). Similarly, when discussing the challenges faced by the ACC farmers in Tigray, ATA (2017) mentions 'the limited availability of mechanization and low rate of input use, especially in the sesame cluster' (p. 40). The report even goes further to conclude that 'sesame is typically low yielding, even with improved inputs, and cultivated by commercial farmers with large landholdings, which would be costly to cover with recommended inputs' (p. 40).

[17] Explaining the ACC clusters, ATA (2017) states that 'they will become models for learning as Ethiopia intensifies the ACC approach and scales up best practices across the country' (p.32). In showcasing the stories and performance of selected ACC farmers, ATA (2017) e.g. refer to them as 'model farmers' in general, and 'model wheat farmer' or 'model wheat cluster farmer' when specifically recounting achievements and challenges for an ACC farmer who grows wheat (p. 33).

Table 20: Performance of the ACC clusters during the 2016/2017 and 2017/2018 planting seasons

	Maize		Bread wheat		Durum wheat		Teff		Malt barley		Haricot beans	
	2016/17	**2017/18**	**2016/17**	**2017/18**	**2016/17**	**2017/18**	**2016/17**	**2017/18**	**2016/17**	**2017/18**	**2016/17**	**2017/18**
Amhara												
Woredas covered	10	10	10	10			12	12	12	12		
Production (qt)	8,634,989	12,444,270	5,153,197	7,503,682			5,199,330	4,999,860	*19,567*	66,209		
Land cultivated (ha)	152,449	169,837	153,181	167,127			184,648	185,980	2,013	3,104		
Computed AvPrty (qt/ha)	56.64	73.27	33.64	44.90			28.16	26.88	9.72	21.33		
Reported AvPrty (qt/ha)	56.6	-	48.4	-			22.9	-	20.8	-		
Regional AvPrty (qt/ha)	37.79	-	23.8	-			16.99	-	18.79	-		
Productivity gain (%)	**49.78**		**103.36**				**34.79**		**10.70**			
Oromia												
Woredas covered	11	11	22	22	7	7	15	16	15			7
Production (qt)	4,669,567	6,644,934	12,422,701	13,165,674	701,816	1,530,360	5,656,165	4,504,964	1,815,600			504,089
Land cultivated (ha)	103,309	112,626	336,203	321,114	18,077	31,960	371,931	195,868	60,520			26,531
Computed AvPrty (qt/ha)	45.20	59.00	36.95	41.00	38.82	47.88	15.21	23.00	30.00			19.00
Reported AvPrty (qt/ha)	45.2	-	37.0	-	39.0	-	20.8	-	30.0			-
Regional AvPrty (qt/ha)	38.18	-	29.65	-	29.65	-	17.17	-	24.06			-
Productivity gain (%)	**18.39**		**24.79**		**31.53**		**21.14**		**24.69**			
Southern Nations, Nationalities, and Peoples (SNNP)												
Woredas covered			18	18							16	16
Production (qt)			4,663,499	4,896,869							726,243	1,553,569
Land cultivated (ha)			106,760	107,861							41,959	93,635
Computed AvPrty (qt/ha)			43.68	45.40							17.31	16.59
Reported AvPrty (qt/ha)			42.0	-							17.0	-
Regional AvPrty (qt/ha)			25.84	-							16.16	-
Productivity gain (%)			**62.54**								**5.20**	
Tigray												
Woredas covered			13	13			10	10				
Production (qt)			3,447,503	*830,976*			1,166,685	*830,976*				
Land cultivated (ha)			111,858	111,079			57,625	53,248				
Computed AvPrty (qt/ha)			30.82	7.48			20.25	15.61				
Reported AvPrty (qt/ha)			30.6	-			20.1	-				
Regional AvPrty (qt/ha)			19.76	-			14.38	-				
Productivity gain (%)			**54.86**				**39.78**					

NB: Average productivity (yield) is abbreviated to 'AvPrty', which is expressed in quintals per hectare of land (qt/ha). These data, except for 'Computed AvPrty' and 'Productivity gain', are extracted from ATA (2017) and ATA (2019). 'Computed AvPrty' is the ratio between reported production and land cultivated. We rely on the reported (cluster and regional) productivities for calculating productivity gains. There must have been a typo in reporting the *underlined and italicized* production numbers, as discussed in the text. It is also strange that the reported volumes of production of bread wheat and teff in Tigray are exactly the same.

5.5 Upscaling ACC effects: FSSIM-Dev scenarios & modelling assumptions

In this report, we assess the economic implications of scaling up the performance of the ACC cluster *woredas* to the whole respective regions of Ethiopia, using the farm-level FSSIM-Dev model. In particular, we examine the effect of an increase in yields equivalent in size to the yield improvements achieved within the ACC areas (Table 20), assuming that all farmers in the ACC-covered regions are able to perform as well as the cluster farmers in their respective regions. Imposing region- and crop-specific exogenous yield shocks is important, because it is expected that they take into account, to a certain degree, the real possibilities of smallholder farmers having to deal with differences in local climate, soil quality, infrastructure availability, marketing conditions, etc. Our exercise is also in line with the GTP II strategy, where it is indicated that one of the tracks to achieving the envisaged shifts in crops productivities (the projected crop productivity targets are given in Table 5) is 'to raise the productivity level of the majority of farmers to the productivity level attained by model farmers' (National Planning Commission, 2016, p. 121).

However, such an assumption would lead to an overestimation of the effects. Indeed, there is large scope for such a scaling up strategy, given that at the national level, for example, rates of adoption of improved seeds and fertilizers are still low in Ethiopia. Table 21 shows that, although fertilizer usage and application rates and the proportion of area covered by improved seeds and extension services have been increasing over time, there is still high potential for exploiting these modern inputs, including knowledge input, and the inherent complementarities between them, to further increase crop productivity. According to Dercon and Gollin (2019), up until 2010 the increase in cereal production growth was mainly driven by area expansion rather than land productivity (i.e. yields), while only post-2010 (GTP I period) did large yield increases became an important driver of cereal production growth. This is also in line with the gradual intensification of agriculture in Ethiopia as seen in Table 21.

Table 21: Fertilizer, improved seeds, and extension services (all cereals)

	Percent area with modern fertilizer	Quantity kg/ha on fertilized land	Percent area with improved seed	Percent of area covered by extension
1996/1997	33	18	2.3	
1999/2000	38	11	4.5	
2005/2006	40	43	5.3	22
2010/2011	44	47	7.3	21
2014/2015	58	130	11.7	39
2017/2018	60.9	166	13.3	39.4

Source: Authors' calculations for 2017/18 (Table 4) and those of Dercon and Gollin (2019, Table 26.2, p. 458), based on the Central Statistical Agency data.

Before presenting our scenarios, it is useful first to show how the exogenous changes in crop yields reported in Table 20 will be implemented in FSSIM-Dev. One of the important modelling ingredients of the FSSIM-Dev model is that it includes a quadratic yield response to fertilizer application function for each farmer (see section 4.3):

$$y = \mu + \alpha N + \beta N^2 \quad (1)$$

where *y* is yield in kg/ha, *N* is applied fertilizer (i.e. nitrogen) quantity in kg/ha, and μ, α and β are parameters (for simplicity, farm, crop and seed variety dimensions are suppressed).

Given the available information, it is impossible to know exactly how function (1) has changed for the ACC cluster farmers, which in our scenario assessment is further complicated by the fact that such changes need to be defined for every farmer producing the specific crops covered by the ACC initiative in the targeted regions. Since it would be highly subjective to define how exactly μ, α and β have changed due to the ACC initiative, we assume two 'extreme' cases:

(1) shift: the imposed yield growth is fully captured by the parallel upward shift in the fertilizer response function, i.e. only the shift parameter μ is shocked; and
(2) slope: the exogenous yield growth is achieved by increasing the yield responsiveness to (i.e. marginal product of) fertilizer use; that is, only α and β are changed.

To determine the exact nature of required changes in these parameters, we need to know the quantities of fertilizer used after the ACC intervention, but this information is not available; therefore we prefer to avoid using ad hoc assumptions on nitrogen use. Because of the missing fertilizer costs and/or fertilizer quantity application changes due to the ACC initiative, we assume that the resulting yield change due to ACC initiative reported in Table 20 is obtained with the same level of fertilizer. This is to say, at the moment we are unable to model the upward movement along the new fertilizer response function (i.e. represented by a movement from point D to E in Figure 20) caused by reduced (explicit and implicit) costs of fertilizer and/or increased/stable output prices obtained from the contract farming arrangements[18].

Since the level of fertilizer is assumed to be the same, determining the change in μ corresponding to extreme case 1 is straightforward. If we denote the change in yield, expressed in decimal number, by Δy, then we need to arrive at $(y_1 - y_0)/y_0 = \Delta y$, where y_0 and y_1 are, respectively, the crop yields before and after policy intervention. Substituting (1) in the last expression gives:

$$(\mu_1 + \alpha N + \beta N^2) - (\mu_0 + \alpha N + \beta N^2) = \Delta y \times y_0, \text{ hence:}$$

$$\Delta\mu = \Delta y \times y_0. \qquad \text{(extreme case 1)}$$

Determining the changes in the slope parameters of (1) corresponding to extreme case 2 is a little more complicated. One needs two equations in order to find the new values of α and β. These are derived from the following system of equations:

$$\begin{cases} \alpha + 2\beta N_0 = r \\ \mu_0 + \alpha N_0 + \beta N_0^2 = (1 + \Delta y) \times y_0 \end{cases} \qquad (2)$$

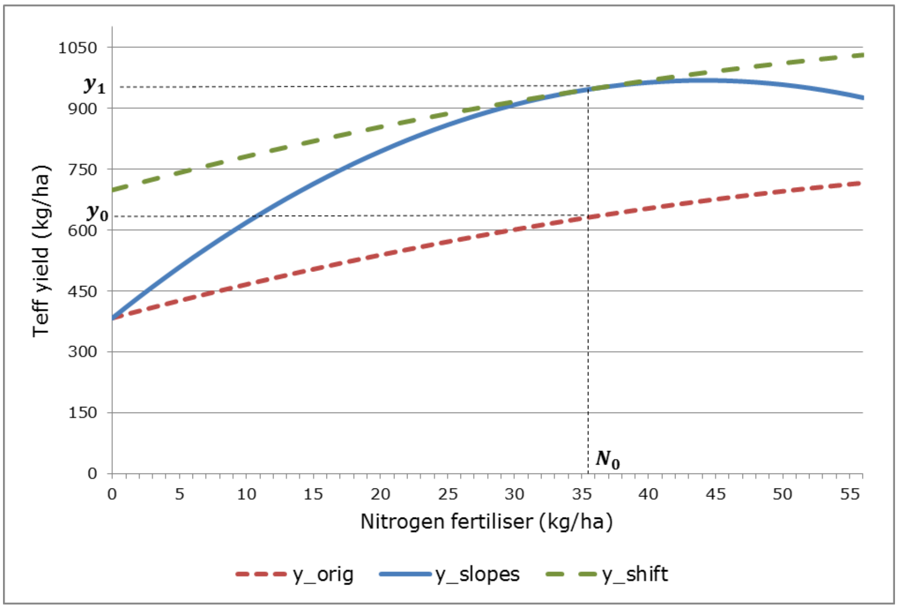
where the ratio of nitrogen price to output price is denoted by $r \equiv p_N/p$, which is known and given to the farmer. The first equation in (2) is the optimality condition for the farmer maximizing her/his profit, which equates to the marginal product of fertilizer to the ratio of fertilizer-to-output prices (or, equivalently, the typical equality of marginal revenue to marginal cost condition: marginal product value of fertilizer = price of fertilizer). The second equation in (2) sets the value of the fertilizer response function after policy intervention to the exogenously specified yield value. Note that the optimal fertilizer use is restricted to exactly equal to its observed level as applied by the farmer. Solving (2) for α and β results in the following expressions that are used in our simulations, where only the slopes of fertilizer response functions are assumed to change:

$$\alpha = 2\frac{(1 + \Delta y) \times y_0 - \mu_0}{N_0} - r \quad \text{and} \quad \beta = -\frac{(1 + \Delta y) \times y_0 - \mu_0 - rN_0}{N_0^2}. \qquad \text{(extreme case 2)}$$

For illustration of these two cases, consider the fertilizer response function for teff of the form $y = 383.03 + 8.781N - 0.0507N^2$, where the coefficients are the averages of the respective parameters of teff (with conventional seed) yield response functions for all Ethiopian farmers, as used in the FSSIM-Dev model (see Table 17). Assuming that $r = 5.18$ (based on the average national output price of ETB 11 per kg of teff and the average fertilizer price of ETB 57 per kg of nitrogen) and $\Delta y = 0.5$ (i.e. yields are assumed to increase by 50%), we get the new fertilizer response functions illustrated in Figure 21. Under the assumed conditions, the optimal quantity of fertilizer use is roughly N_0 = 35.5 kg/ha for all fertilizer response functions. It is the exact point where the two new fertilizer response functions meet in Figure 21. The corresponding teff yields are roughly y_0 = 630.8 kg/ha before, and y_1 = 946.2 kg/ha after, the intervention. Note that the slopes of the fertilizer response function corresponding to the case where only the slope coefficients have been shocked are always higher (in absolute value) for all non-optimal quantities of fertilizer use, compared with those where only the shift parameter has been changed. This implies that in the first case there will be a lower reaction in terms of fertilizer use by a rational farmer in response to a given change in fertilizer cost and/or teff output price.

[18] In fact, the contract farming arrangements did not work equally as expected in all regions. For example, in the case of Tigray, 'the performance of contract farming was low because some farmers refused to supply their crops through contract farming arrangements as the prices were lower than their expectation. They instead stored their products for a long time until prices are higher. Furthermore, the high interference of brokers with the contract agreements, the inability of buyers to fully finance and pay on time to producers, the limited aggregation capacity of primary cooperative, unions and agro-processors are all challenges for the expansion of contract farming. This experience highlights the need for significant education, structures and regulations related to all actors within the supply chain to ensure that a clear and efficient contracting arrangement is created between farmers and buyers' (ATA, 2019, pp. 42-43).

Figure 21: Teff yield to fertilizer use response functions, before and after an exogenous 50% increase in yield



NB: The original, with increase in slopes only, and with increase in intercept only fertilizer response functions are denoted, respectively, by y_orig, y_slopes and y_shift.

The region-specific productivity shocks imposed in the FSSIM-Dev model are presented in Table 22; except for two cases these are the same productivity gains presented in Table 20. First, the wheat yield changes for Oromia are the averages of the yield gains computed for bread wheat and durum wheat. Second, the yield gain of 103.36% for wheat in Amhara found in Table 20 seems rather high (also when compared to the relevant GTP II targets summarized in Table 5), and thus unrealistic to impose on all farmers in the region. Given that the overwhelming majority of reported productivities in Table 20 are pretty close to the computed productivities, we have thus decided to use computed average productivity (33.64 qt/ha) instead of its reported counterpart (48.4 qt/ha). This resulted in approximate productivity gain for wheat-growing cluster farmers of 41.35% (=33.64/23.8-1). The latter figure is thus used in our simulations, instead of 103.36%. Note that the yield changes are imposed on smallholder farmers only in the four largest agricultural regions of Ethiopia, where the ACC initiative was/is in place.

Table 22: Yield changes (%) included in simulation scenarios

	Amhara	Oromia	SNNP	Tigray
Maize	49.78	18.39		
Wheat	41.35	28.16	62.54	54.86
Teff	34.79	21.14		39.78
Barley	10.70	24.69		
Haricot beans			5.20	

Source: Based on the ACC performance data presented in Table 20.

Now in order to impose the exogenously specified productivity changes (Table 22) within the FSSIM-Dev model, two additional issues (scenario dimensions) have to be considered. First, we need to have two separate scenarios reflecting the two 'extreme' options for implementing the yield shocks, through respective changes in the parameters of the yield response function as discussed above.

The second issue is related to whether it is reasonable to increase productivity of all farms, irrespective of which seed types have been used in growing the crops under consideration. One may think that it is not reasonable to impose exactly the same productivity improvements on farms with improved seeds vis-a-vis farms with conventional seeds only, on the grounds that the first already have access to the new technology represented by improved seed use. Nonetheless, there is still scope for yield improvement, albeit to a possibly lower degree, even for farms with improved seeds - if non-optimal management (agronomic) practices are still in place. We therefore consider two additional 'extreme' cases, representing seed types: (1) yields are increased for all farms, irrespective of seed types; and (2) yields are increased only for farms with conventional seeds. To summarize, we end up with the following four scenarios:

1. **Shift_AllSeeds**: we move up the yield curves parallel to the original ones for all farms in the four regions and all seed types, corresponding to the 2016/17 region- and crop-specific productivity changes as summarized in Table 22.
2. **Shift_ConvSeed**: we move up the yield curves parallel to the original ones for all farms in the four regions but only for conventional seeds, corresponding to the 2016/17 region- and crop-specific productivity changes as summarized in Table 22.
3. **Slope_AllSeeds**: we move up the yield curves by changing their slopes for all farms in the four regions and all seed types, corresponding to the 2016/17 region- and crop-specific productivity changes as summarized in Table 22.
4. **Slope_ConvSeed**: we move up the yield curves by changing their slopes for all farms in the four regions but only for conventional seeds, corresponding to the 2016/17 region- and crop-specific productivity changes as summarized in Table 22.

6 Results of the ACC upscaling scenarios

6.1 Land use and production effects

The impacts on crop-specific land use (i.e. crop allocation) of the four simulated scenarios, compared to the corresponding baseline cultivated area, are illustrated in Figure 22 - for Ethiopia as a whole and for its four main agricultural regions. As can be seen from this figure, the impact on land use is generally quite minor. Among the targeted crops, at the country level, land use impact is found to be highest for maize: in the case of the Shift_AllSeeds scenario, maize area increases by 0.52%. The corresponding regional details in Figure 22 show that this change can be traced to Amhara and Oromia, with respective increases in maize area for the Shift_AllSeeds scenario of 1.30% and 0.41%. This is an expected outcome, since maize productivities for farmers specifically in these two regions were shocked in our simulations (Table 22).

Higher yields generally imply greater profits from growing the targeted crops; hence in Figure 22, we observe area being reallocated from other crops to maize, wheat and teff. However, the effects of these reallocated areas are small, at least at national level. The largest decrease in land use is found for chat (-0.81% for Ethiopia as a whole) in the case of the Shift_AllSeeds scenario, which basically originates from one region - Oromia (-1.16%). This implies that the yield increase is not sufficient to lead to strong land reallocation. The average impacts on land use across all four scenarios are presented in Table 23.

Table 23: Land use change, average impacts across all scenarios (% change relative to the baseline)

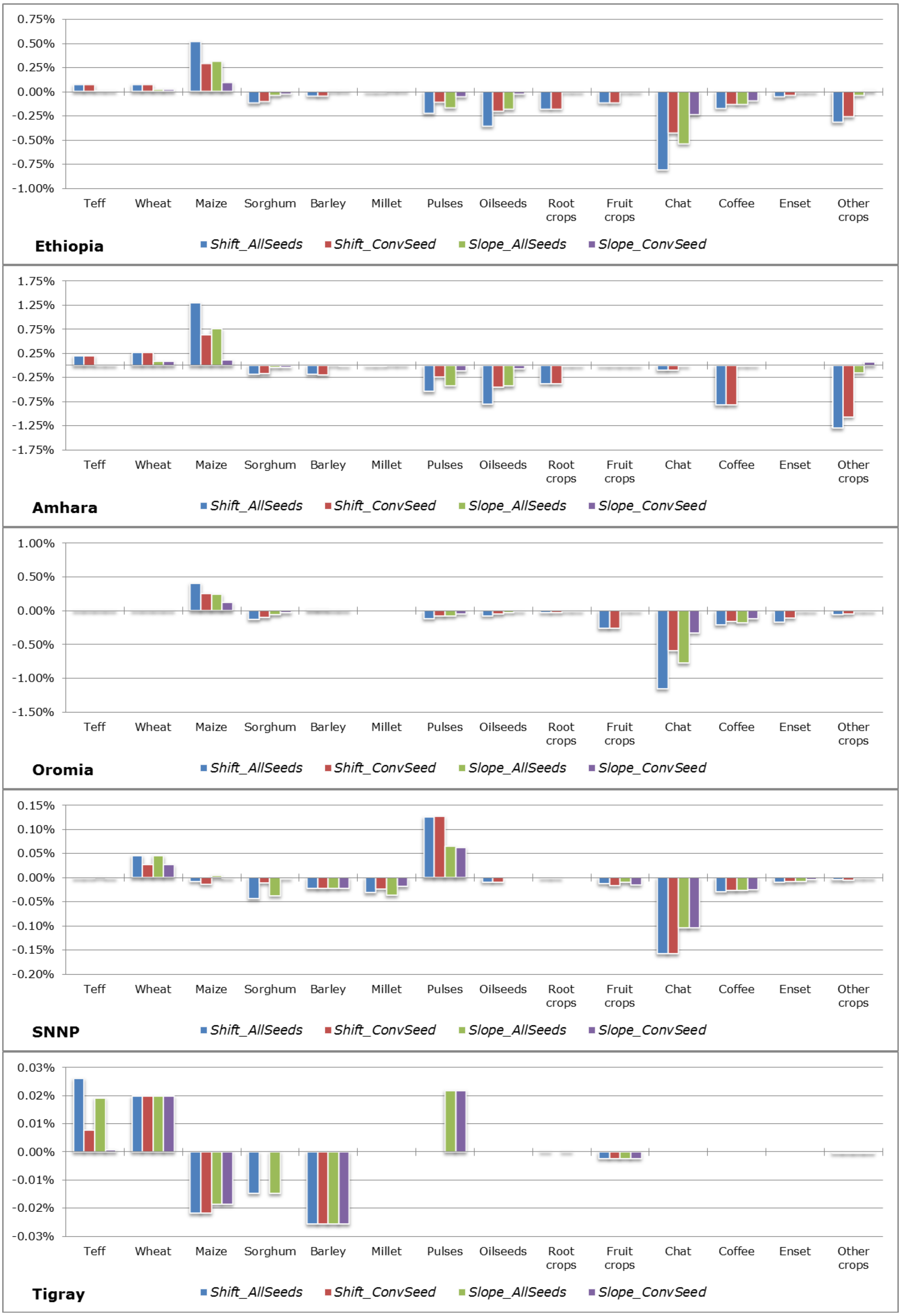
	Ethiopia	Amhara	Oromia	SNNP	Tigray
Teff	0.04	0.11	0.01	0.00	0.01
Wheat	0.05	0.18	0.00	0.04	0.02
Maize	0.30	0.70	0.26	0.00	-0.02
Sorghum	-0.07	-0.11	-0.08	-0.02	-0.01
Barley	-0.02	-0.10	0.02	-0.02	-0.03
Millet	0.00	0.00	0.00	-0.03	0.00
Pulses	-0.14	-0.33	-0.08	0.10	0.01
Oilseeds	-0.19	-0.44	-0.04	0.00	0.00
Root crops	-0.09	-0.19	-0.01	0.00	0.00
Fruit crops	-0.06	-0.01	-0.13	-0.01	0.00
Chat	-0.50	-0.05	-0.71	-0.13	0.00
Coffee	-0.13	-0.41	-0.17	-0.03	0.00
Enset	-0.03	0.00	-0.07	-0.01	0.00
Other crops	-0.15	-0.61	-0.03	0.00	0.00
Fallow	0.00	0.01	0.00	0.00	0.00

Source: Model results.

It can also be observed from Table 23 that the land use change occurs within the cultivated area and there is no (or very minor) land expansion, since the area under fallow land remains (basically) unchanged. It is important to recall, firstly, that fallow land is available only on a few farms and, secondly, that putting fallow land into production is assumed to incur costs. To better understand the relative contribution of land use to production change, we present the production impacts in Table 24. Again, as expected, large changes in production are observed only for the targeted crops, namely teff, wheat, maize and barley. An exogenous 5.20% increase in the productivity of haricot beans in SNNP (Table 22) is reflected in an increase in regional production of the corresponding aggregate crop item of Pulses, ranging between 0.9% and 1.9% across scenarios; however, at the country level there is practically no change.

Moreover, from Table 24 it clearly appears that, for the majority of scenarios, the percentage change in production of the targeted crops is close to the exogenously specified percentage changes in the respective crop yields (Table 22). This means that production change is mainly driven by increase in land productivity, rather than area expansion or area reallocation. The exception is maize, where the rise in production is partially explained by increase in land under maize.

Figure 22: Land use change under simulated scenarios (% change relative to the baseline)



To better understand this relation, let us first decompose production change into two effects: land productivity effect and (cultivated) area effects, which follows from:

$$\text{Production} = \left(\frac{\text{Production}}{\text{Area}}\right) \times \text{Area} = \text{Productivity} \times \text{Area}\ ,$$

where *Area* stands for cultivated area and for simplicity the crop index is suppressed. We did not include the crop intensity effect, i.e. (Harvested area)/(Arable land), since fallow land area remains unchanged under all our ACC scenarios. Therefore, production impacts are decomposed into productivity and area effects (all expressed in tonnes) in an additive form as follows:

$$\Delta\text{Production} = \Delta\text{Productivity} + \Delta\text{Area}\ ,$$

where $\Delta \text{x} = \text{x(scenario)} - \text{x(baseline)}$. The Logarithmic Mean Divisia Index (LMDI) approach (see e.g. Ang, 2005) is used to calculate the individual contributions above. For example, the area effect is calculated as follows:

$$\Delta\text{Area} = \frac{\text{Prod\_S} - \text{Prod\_B}}{\ln(\text{Prod\_S}) - \ln(\text{Prod\_B})} \times \ln\left(\frac{\text{Area\_S}}{\text{Area\_B}}\right),$$

where Prod_S and Prod_B refer to, respectively, production (in tonnes) under the ACC scenario and baseline scenario, *ln* stands for natural logarithm, and Area_S and Area_B denote the cultivated area under the ACC and baseline scenarios, respectively.

The decomposition results, in terms of percentage contributions of productivity and area effects to crop production change in the ACC scenarios considered, are presented in the bottom part of Table 24 for the most affected crops (teff, wheat, maize and barley). The results show that production impacts are mainly driven by productivity increases, which account for at least 87% of crop production change. As an example, consider the maize production increase of 51.5% in Amhara under the Shift_AllSeeds scenario, which is larger than the relevant exogenous productivity shock of 49.78% (Table 22). The decomposition results tell us that productivity improvement accounts for 95.84% of the total change in maize production in Amhara, and the remaining 4.16% is attributed to the impact of area expansion. Since the productivity effects explain most of the changes in production under all ACC scenarios, it is not surprising to observe that production impacts under the Shift_AllSeeds scenario are close to the ACC productivity improvement shocks imposed exogenously.

Table 24 shows that the area effect is non-negligible only for maize production, in the regions concerned and for the country as a whole, and for barley production in Amhara. It is interesting to note that in the latter case, the area effect has a negative impact on barley production. Take, for example, the Shift_ConvSeed scenario, where the yield response functions for Amhara's barley-growing farmers using conventional seeds only are shifted upward by 10.70%. According to the FSSIM-Dev model, this intervention results in a 10.4% increase in barley production in the region, which is entirely driven by productivity effect: in fact, productivity improvement explains 105.33% of the change in barley production, but the shrinking barley area effect (due to crop area reallocation by profit-maximizing household farmers) absorbs or counterbalances 5.33% of the original yield-driven production impact.

Table 24: Production change decomposition (i.e. yield and area effects) for most affected crops

	Ethiopia				Amhara				Oromia				SNNP				Tigray			
	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed
	Production change (% of baseline production)																			
Teff	24.8	24.1	18.1	17.4	35.2	33.9	23.0	21.8	21.2	20.9	16.7	16.5	0.0	0.0	0.0	0.0	39.8	36.8	34.9	31.8
Wheat	34.4	31.0	28.0	24.8	41.7	37.5	25.9	22.1	28.2	27.1	24.7	23.7	62.6	45.3	56.0	39.3	54.9	39.8	44.9	30.4
Maize	24.2	8.5	16.5	2.2	51.5	15.7	39.8	4.7	19.3	7.8	10.9	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Barley	16.6	16.2	8.8	8.6	10.5	10.4	2.9	2.9	24.8	24.1	14.6	14.3	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1
Sorghum	-0.2	-0.1	0.0	0.0	-0.2	-0.2	0.0	0.0	-0.2	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Millet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pulses	0.0	0.1	0.0	0.0	-0.3	-0.2	-0.2	0.0	-0.1	-0.1	-0.1	-0.1	1.9	1.9	0.9	0.9	0.0	0.0	0.0	0.0
Oilseeds	-0.2	-0.1	-0.1	0.0	-0.4	-0.2	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Root crops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fruit crops	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
Chat	-0.5	-0.4	-0.2	-0.2	-0.1	-0.1	0.0	0.0	-0.6	-0.5	-0.4	-0.3	-0.4	-0.4	-0.1	-0.1	0.0	0.0	0.0	0.0
Coffee	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.0	0.0	-0.3	-0.3	-0.3	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Enset	0.0	0.0	0.0	0.0					-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0				
Other crops	-0.1	-0.1	0.0	0.0	-0.7	-0.7	-0.1	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Productivity effect (% of Production change expressed in physical unit)																			
Teff	99.57	99.56	99.82	99.82	99.09	99.06	99.63	99.62	99.94	99.94	99.94	99.94					99.95	99.98	99.96	100.0
Wheat	99.45	99.41	99.78	99.77	98.20	98.04	99.21	99.10	99.99	99.98	99.99	99.99	99.93	99.92	99.86	99.91	99.95	99.94	99.95	99.93
Maize	96.31	94.10	97.06	92.96	95.84	93.92	97.02	96.58	95.92	93.52	96.22	88.62								
Barley	101.0	101.1	100.2	100.2	105.2	105.3	101.4	101.9	99.95	99.95	99.98	99.98								
	Area effect (% of Production change expressed in physical unit)																			
Teff	0.43	0.44	0.18	0.18	0.91	0.94	0.37	0.38	0.06	0.06	0.06	0.06					0.05	0.02	0.04	0.00
Wheat	0.55	0.59	0.22	0.23	1.80	1.96	0.79	0.90	0.01	0.02	0.01	0.01	99.93	99.92	99.86	99.91	0.05	0.06	0.05	0.07
Maize	3.69	5.90	2.94	7.04	4.16	6.08	2.98	3.42	4.08	6.48	3.78	11.38								
Barley	-1.03	-1.09	-0.17	-0.22	-5.16	-5.33	-1.41	-1.91	0.05	0.05	0.02	0.02								

NB: The additive decomposition of production change into productivity (yield) and area effects is based on the Logarithmic Mean Divisia Index (LMDI) approach. *Source*: Model results

As expected, the largest production change is obtained under the Shift_AllSeeds scenario, where the yield to fertilizer use response functions are shifted up for all farmers, irrespective of seed type used. The differences across scenarios that target all farmers, vs farmers with conventional seeds only, reflect the prevalence of improved seed use for the crop and region under consideration. For example, since improved seeds are extensively used in maize production (Figure 9), production impacts under scenarios that target farmers using both conventional and improved seeds are larger than when targeting farmers using conventional seeds only. This outcome is also true for wheat production in SNNP and Tigray, because many wheat-growing farmers in these regions also extensively use improved seeds (Figure 9).

For almost all other crops, as shown in Table 24, the largest changes occur under the Shift_AllSeeds scenario, followed by Shift_ConvSeed, then Slope_AllSeeds and finally the Slope_ConvSeed scenario. Thus, in these cases moving up the yield curves parallel to the original ones results in a higher production change, in comparison to changing only the slope of the yield curve.

Table 25 shows a summary of production impacts, averaged over all the ACC scenarios considered. These average figures from our modelling exercises confirm the general expectation that scaling up the ACC policies to non-cluster household farmers in the ACC-covered regions would have a positive production impact on the targeted crops. Furthermore, these potential production effects can largely be achieved through an increase in land productivity (i.e. more intensification) and thus without major impacts on the production of non-targeted crops.

Table 25: Production change, average across all scenarios (% change relative to the baseline)

	Ethiopia	Amhara	Oromia	SNNP	Tigray
Teff	21.10	28.47	18.81	0.00	35.81
Wheat	29.55	31.80	25.94	50.83	42.47
Maize	12.84	27.93	9.95	-0.01	-0.02
Barley	12.55	6.68	19.45	-0.03	-0.05
Sorghum	-0.09	-0.08	-0.14	-0.01	-0.01
Millet	0.00	0.00	0.00	-0.03	0.00
Pulses	0.01	-0.17	-0.07	1.37	0.01
Oilseeds	-0.08	-0.20	-0.01	0.00	0.00
Root crops	-0.01	-0.02	0.00	0.00	0.00
Fruit crops	-0.03	-0.02	-0.02	-0.08	0.00
Chat	-0.30	-0.03	-0.42	-0.24	0.00
Coffee	-0.17	-0.10	-0.30	-0.03	0.00
Enset	-0.02		-0.05	-0.01	
Other crops	-0.07	-0.37	-0.03	0.00	0.00

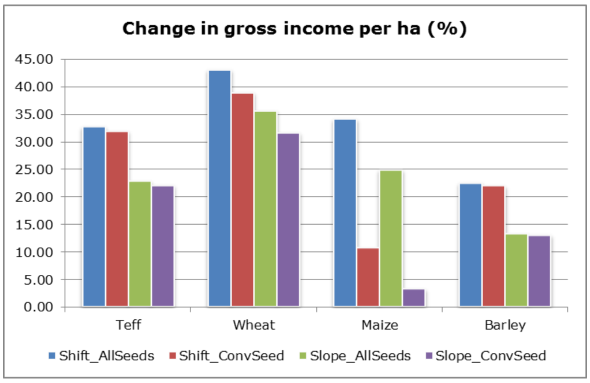
NB: The figures are arithmetic averages of production impacts across all four ACC scenarios considered, which are presented in Table 24.
Source: Model results.

6.2 Income and poverty effects

The effect on farm household income is another key component for evaluating the effectiveness of any agricultural policy in developing countries. The changes in gross and net income intensities[19] (ETB per ha, weighted and scaled up to the country level) for the targeted crops due to the ACC policies are illustrated in Figure 23, while those for all crops and regions are presented in Table B.1 and Table B.2 in appendix. The land use and production effects induced by ACC interventions reported above largely explain these income changes.

[19] Gross income (or gross margin) is defined as total revenue from sales and self-consumption of agricultural products minus the accounting variable costs of production activities. Net income is gross income minus implicit costs (i.e. PMP terms), defined as quadratic activity-specific function, that are introduced to calibrate the farm model to the observed production activities. For more details, see section 3.1.

Figure 23: Gross income and net income intensities under simulated scenarios (% change relative to the baseline)



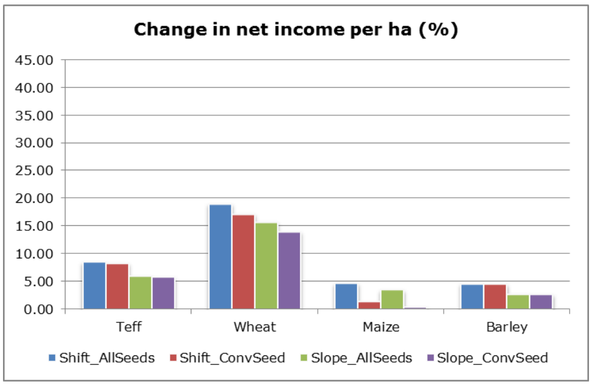


Figure 23 shows that, as expected, the gross and net income intensities of the targeted crops have all increased due to the ACC policy intervention. The increase in net income per ha is, however, much lower because a fairly large part of net income is spent on implicit costs (i.e. capital constraint and other unobserved costs that are captured by the PMP terms).

The gross income impacts at the country and regional level are presented in Table 26. It is found that scaling up of the ACC policies to the respective regional level would increase income at the country level by between 10.2% and 18.9%, depending on the scenarios considered. Average gross income increase across all scenarios is estimated at about 14%. Regions most positively affected are Amhara and Oromia, namely because in these regions improved productivity shocks were implemented for all four targeted cereals (maize, wheat, teff and barley) (Table 22).

Table 26: Gross income change under simulated scenario (% change relative to the baseline)

	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed	Average across all scenarios
Ethiopia	18.90	14.68	14.12	10.23	14.48
Amhara	22.71	15.42	15.20	8.08	15.35
Oromia	20.40	17.40	15.94	13.47	16.80
SNNP	8.85	6.36	8.03	5.62	7.22
Tigray	14.92	12.26	12.57	10.00	12.44

Source: Model results.

One of the advantages of the FSSIM-Dev model is that all the results are driven by decisions made at individual household-farm level. Hence, one can zoom in to see the effects at individual farm level. Figure 24 shows the distribution of gross income change across individual farms, while the summary statistics of both gross and net income changes for all 2,886 farms are given in Table 27. In the Shift_AllSeeds, Shift_ConvSeed, Slope_AllSeeds and Slope_ConvSeed scenarios, the gross income of, respectively, 41.6%, 44.1%, 64.5% and 68.4% of household farmers remains unchanged compared with the corresponding baseline gross incomes. This is reflected in median figures for gross income changes given in Table 27, and the starting points for the cumulative distributions of gross income changes in Figure 24(b) (the second subplot zooms in to more vividly show the differences between the four scenarios in the distribution of gross income changes for the affected farms)[20].

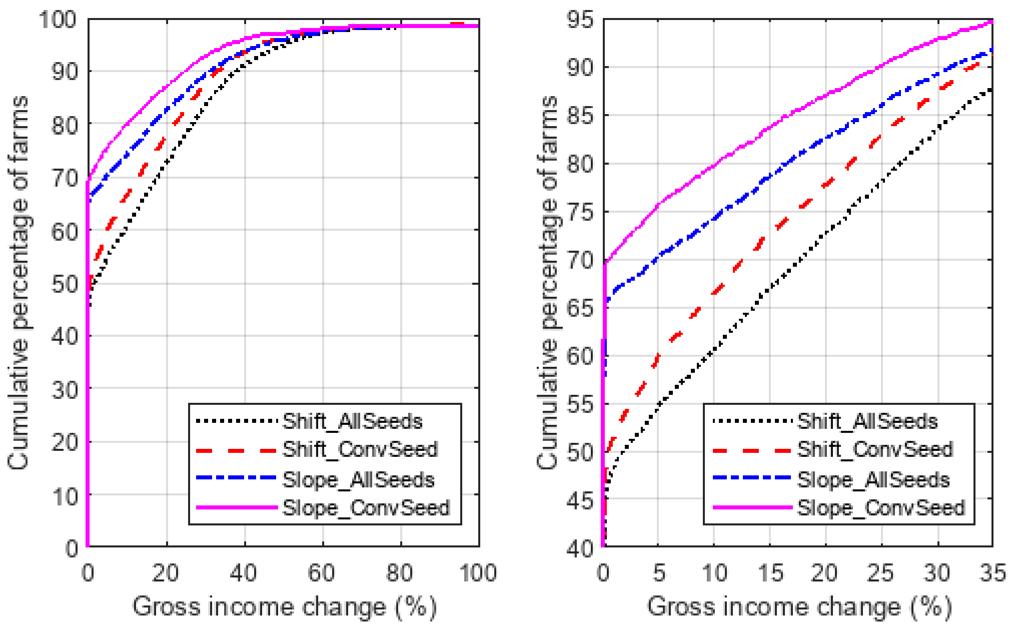
[20] For the scenarios considered, the first subplot of Figure 244 includes from 99.3 to 99.5% of all farms, excluding a few 'outliers' with large increases in gross incomes, in order to better illustrate the differences in the resulting distributions.

Table 27: Summary statistics of farm-level changes in gross and net incomes (% change relative to the baseline)

	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed	*Average*
	Gross income change				
Mean (all farms)	12.82	10.59	8.03	5.98	*9.35*
Mean (affected farms)	21.57	18.65	21.85	18.25	*20.08*
Median (all farms)	1.26	0.40	0.00	0.00	*0.42*
Median (affected farms)	17.21	13.53	16.92	13.84	*15.37*
Standard deviation	51.23	46.93	46.24	42.34	*46.69*
	Net income change				
Mean (all farms)	3.40	2.77	2.43	1.84	*2.61*
Mean (affected farms)	6.05	5.16	6.99	5.98	*6.04*
Median (all farms)	0.09	0.03	0.00	0.00	*0.03*
Median (affected farms)	2.46	1.86	3.05	2.22	*2.40*
Standard deviation	8.49	7.39	7.85	6.68	*7.60*

Source: Model results.

Figure 24: Distribution of farm-level gross income change (% change relative to the baseline)



(a) All farms (b) Affected farms

Table 27 shows that the average increase in gross income for all farms ranges from 6.0% to 12.8%, depending on the scenario considered. The corresponding changes in net income are much smaller, ranging between 1.8% and 3.4%. The smaller change in net income compared to gross income is explained by the fact that implicit costs (captured by PMP terms) increase with the increase in production driven by productivity and area effects. If one focuses on affected household farms only (those with non-zero changes), the average increase in gross income is found to range between 18.3% and 21.9%. The corresponding average net income changes are only between 5.2% and 7.0%. The median income changes for the affected farms are assessed to range between 13.5% and 17.2% for gross income, and between 1.9% and 3.1% for net income, both indicating that the increase in income for half the affected farms is evaluated to be smaller. The full picture of gross income changes across all farmers is captured by the corresponding distributions in Figure 24.

The distributions in Figure 24 show that, for a given cumulative share of farms, the following relation in terms of changes in gross income is observed: the lowest income change is observed under the Slope_ConvSeed scenario, followed by Slope_AllSeeds, then Shift_ConvSeed and finally Shift_AllSeeds. For example, 85% of farms experience an increase in their gross income of up to 16.9%, 23.8%, 27.4% and 31.7% under the

Slope_ConvSeed, Slope_AllSeeds, Shift_ConvSeed and Shift_AllSeeds scenarios, respectively. This is again an expected outcome, since under for example the Shift_AllSeeds scenario, all farmers irrespective of seed type used are assumed to experience an exogenous productivity improvement. These distributional findings also explain the aggregate income impacts under the different scenarios discussed earlier and shown in Table 26.

Next, the estimated changes in gross income by farm type are shown in Table 28. The largest income change is experienced by farms specializing in field crops, which is not surprising as the ACC targeted crops considered are field crops. Farm households specializing in permanent crops gain a small increase in income of roughly 1.1% on average.

Table 28: Gross income change by farm type (% change relative to the baseline)

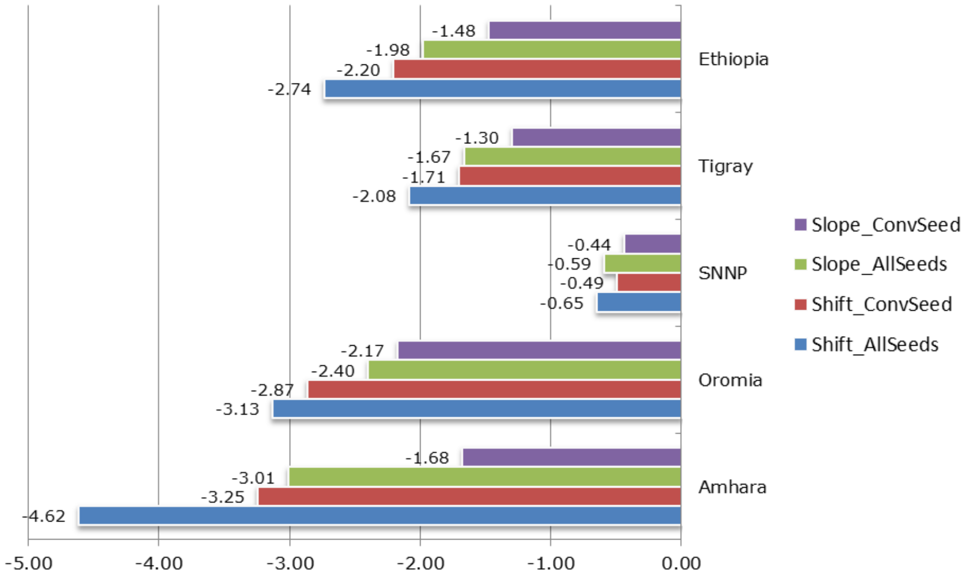
	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed	Average across all scenarios
	Farm specialization				
Field crops	17.99	14.72	13.12	10.10	13.98
Permanent crops	1.44	1.11	1.00	0.68	1.06
Mixed	10.17	6.63	7.32	3.92	7.01
	Economic size				
ES1 (<ETB 4000)	7.87	6.55	5.13	3.88	5.86
ES2 (ETB 4000-9000)	12.70	9.57	8.13	5.19	8.90
ES3 (>ETB 9000)	15.74	12.68	12.05	9.22	12.42
	Farm specialization and economic size				
Field & ES1	11.48	9.37	7.49	5.43	8.44
Field & ES2	16.94	12.86	10.87	7.02	11.92
Field & ES3	19.45	16.28	14.89	12.03	15.66
Permanent & ES1	0.99	0.70	0.83	0.56	0.77
Permanent & ES2	1.43	1.08	0.85	0.50	0.96
Permanent & ES3	1.57	1.24	1.10	0.77	1.17
Mixed & ES1	6.86	6.06	4.33	3.67	5.23
Mixed & ES2	7.46	5.34	4.75	2.81	5.09
Mixed & ES3	14.17	7.95	11.02	4.90	9.51

Source: Model results.

In terms of economic size, the largest increase in gross income is experienced by medium-large farms (i.e. farms with economic size > ETB 9,000), followed by small farms (with economic size of ETB 4,000-9,000). The average income gains across all scenarios are found to be 12.4%, 8.9% and 5.9% for, respectively, medium-large farms, small farms and subsistence farms. These average figures increase, respectively, to 15.7%, 11.9% and 8.4% if one focuses on farms specializing in field crops by their economic size. The heterogeneity of income change across different economic sizes is not surprising either, given that the increase in land productivity under AAC interventions is higher in medium-large farms than in small farms.

Finally, the region- and country-level results for extreme poverty impacts are presented in Figure 25. The extreme poverty gap indicator measures the difference between farm household income per household unit and the extreme poverty line of USD 1.90 equivalent per person per day (ETB 55). As expected, the extreme poverty gap decreases through scaling up the ACC policies: on average across all four scenarios considered, the extreme poverty gap is assessed to decrease by about 2.1% throughout the country, while the corresponding region-specific average poverty effects in Amhara, Oromia, SNNP and Tigray are found to be, respectively, -3.1%, -2.6%, -0.5% and -1.7%.

Figure 25: Change in extreme poverty (% change relative to the baseline)



6.3 Food consumption and nutrition effects

The impacts of the ACC policies considered on Ethiopia's total consumption, according to the FSSIM-Dev simulations, are illustrated in Figure 26. The average impacts across all four scenarios, including those for the main agricultural regions of Ethiopia, are presented in Table 29, while the corresponding detailed results for all scenarios are given in Table B.3 in appendix. As explained in the previous section, an increase in the production of targeted cereals led to an increase in income. These production and income effects are expected to have a positive impact on farm household consumption, which is exactly what our results show. Countrywide on average, across all scenarios, the ACC productivity improvements in wheat, maize, teff and barley led to an increase in total consumption of these crops of, respectively, 3.2%, 3.0%, 2.1% and 2.2% (Table 29).

Figure 26: Change in total consumption under simulated scenarios (% change relative to the baseline)

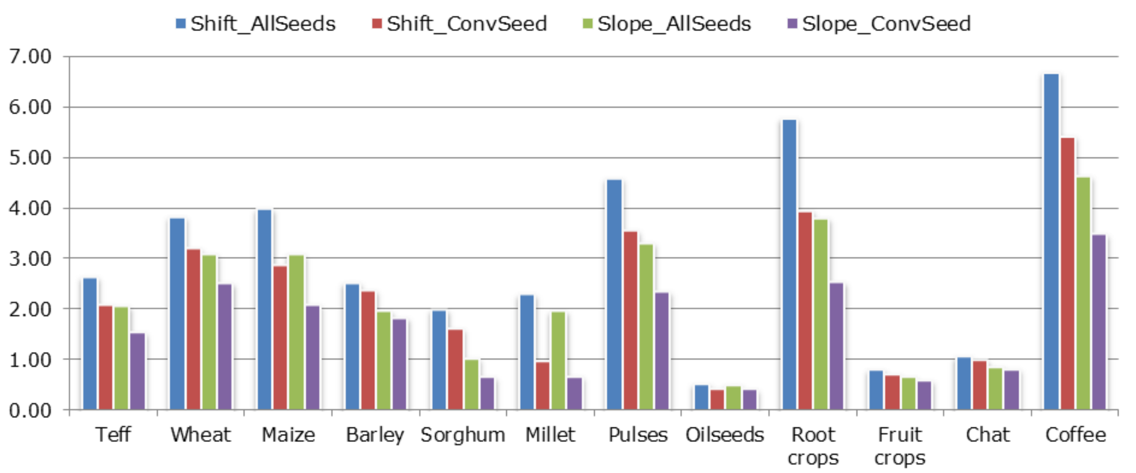


Table 29: Total consumption change, average across all scenarios (% change relative to the baseline)

	Ethiopia	Amhara	Oromia	SNNP	Tigray
Teff	2.08	2.54	2.23	0.37	2.10
Wheat	3.16	4.15	3.60	1.26	2.23
Maize	3.01	4.44	3.44	1.75	6.17
Barley	2.17	1.06	3.21	0.29	1.30
Sorghum	1.32	1.26	1.57	0.80	1.71
Millet	1.47	2.22	0.31	-0.02	0.16
Pulses	3.45	5.02	3.58	1.57	2.24
Oilseeds	0.46	0.78	0.32	0.03	0.49
Root crops	4.02	4.32	6.09	0.88	1.97
Fruit crops	0.68	0.14	1.44	0.16	0.15
Chat	0.93	0.13	1.33	0.05	0.01
Coffee	5.06	8.72	6.22	2.07	4.30

Source: Model results.

However, since household income is positively affected, they then also consume more non-targeted crops. Among these, the highest impact is observed for coffee, root crops and pulses, with countrywide average (across all scenarios) increase in total consumption of, respectively, 5.1%, 4.0% and 3.5%. This is explained by the relatively high income elasticities for these consumption categories used in the FSSIM-Dev model. Our income elasticities for all food and non-food items are reported in Table A.4.

The change in total consumption can be decomposed into changes in purchased consumption and in own-produced consumption (since consumption from other sources was kept constant in simulations). Figure 27 shows the countrywide impacts on these two sources of consumption and sales under all four scenarios. The average impacts across these scenarios, also at the regional level, are presented in Table 30, and the corresponding detailed results for all scenarios are shown in Table B.4, Table B.5 and Table B.6 in appendix.

As expected, expanded production due to productivity improvement for the targeted crops leads to higher own-produced consumption of these crops, and lower purchases of these crops for consumption purposes. At the same time, it is also not surprising to find an increase in sales at the country or regional level, since a farmer whose production increases will be able not only to consume more from his/her own production, but could also sell the remaining harvest on the market.

Overall in Ethiopia, on average across all four ACC scenarios, purchased consumption decreased between 0.6% and 7.8% for the targeted cereals, while own-produced consumption of these expanded between 7.3% and 13.0% (Table 30). Ethiopian sales are found to increase, on average across all scenarios, between 16.4% and 40.9% for the targeted cereals, but to shrink for the remaining products (from -0.1% to -2.0%). The regional heterogeneity of all these average impacts are detailed in Table 30; these are not discussed further here for space purposes.

Figure 27: Change in consumption sources and sales under simulated scenarios (% change relative to the baseline)

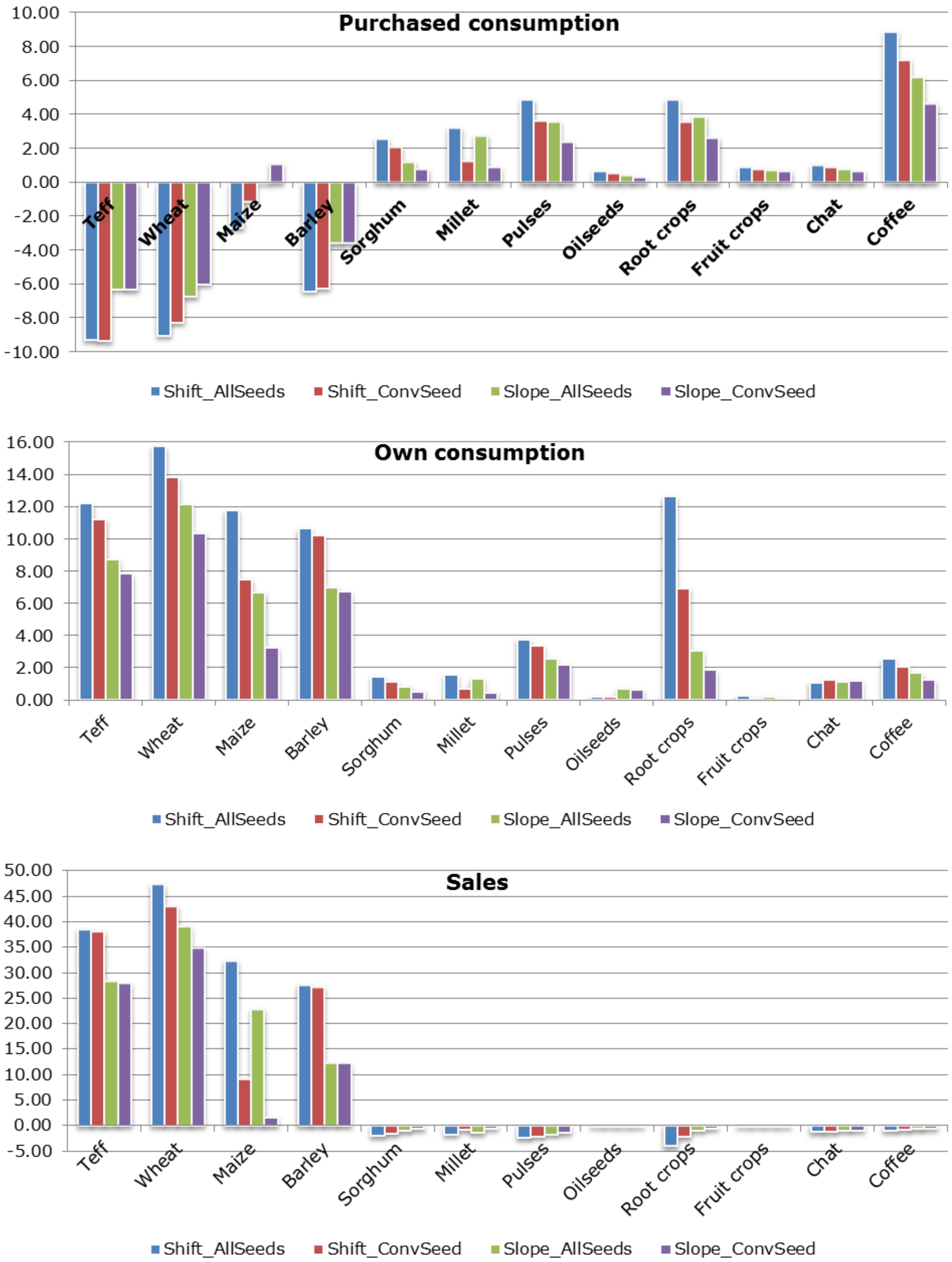


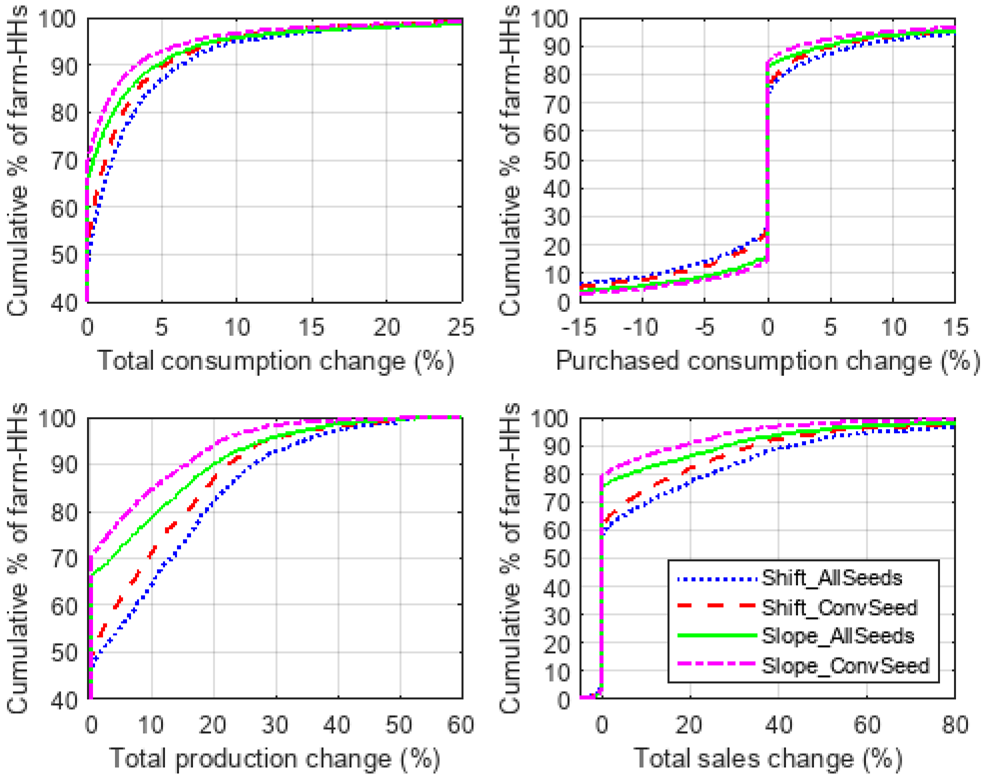
Table 30: Change in consumption sources and sales, average across all scenarios (% change relative to the baseline)

	Ethiopia	Amhara	Oromia	SNNP	Tigray
	Purchased consumption (% change)				
Teff	-7.80	-11.26	-7.73	0.31	-13.74
Wheat	-7.48	-12.08	-5.32	-9.68	-12.46
Maize	-0.66	-8.16	-0.97	0.60	8.42
Barley	-4.93	-2.22	-9.37	0.41	1.51
Sorghum	1.67	1.95	1.72	0.82	2.79
Millet	2.04	3.69	0.44	0.00	0.14
Pulses	3.62	5.67	3.86	1.47	2.52
Oilseeds	0.48	0.71	0.40	0.03	0.38
Root crops	3.75	5.31	5.01	0.90	1.99
Fruit crops	0.76	0.16	1.55	0.19	0.16
Chat	0.84	0.15	1.30	0.05	0.00
Coffee	6.75	9.04	8.64	2.86	4.30
	Own-produced consumption (% change)				
Teff	9.98	10.55	9.37	0.48	25.97
Wheat	13.02	13.16	10.67	21.06	22.42
Maize	7.28	9.15	8.06	5.02	4.03
Barley	8.63	3.99	12.45	0.07	1.02
Sorghum	1.00	0.87	1.42	0.75	0.67
Millet	1.01	1.37	0.12	-0.09	0.20
Pulses	2.98	3.43	2.97	2.30	1.38
Oilseeds	0.43	0.93	0.19	0.00	1.15
Root crops	6.11	0.86	16.63	0.36	0.00
Fruit crops	0.17	0.00	0.49	0.01	0.00
Chat	1.17	-0.02	1.38	0.11	0.06
Coffee	1.89	4.76	2.39	1.12	0.00
	Sales (% change)				
Teff	33.10	43.29	30.49	-0.41	68.77
Wheat	40.92	47.38	34.57	83.36	137.24
Maize	16.41	38.68	11.00	-6.14	-4.27
Barley	19.75	9.17	38.64	-0.29	-1.43
Sorghum	-1.38	-1.02	-2.35	-1.34	-0.92
Millet	-1.14	-1.71	-0.25	0.07	-0.09
Pulses	-1.93	-1.96	-2.38	0.36	-0.94
Oilseeds	-0.11	-0.23	-0.03	0.00	-0.01
Root crops	-1.98	-0.85	-2.33	-0.42	0.00
Fruit crops	-0.06	-0.02	-0.08	-0.10	0.00
Chat	-1.11	-0.04	-3.37	-0.26	0.00
Coffee	-0.81	-1.74	-1.10	-0.41	0.00

Source: Model results.

The farm household level data provide further (micro) explanation of the resulting aggregate impacts. Figure 28 illustrates the distributions (excluding a few outliers) of farm-household level changes in total consumption, purchases, production and sales, while the corresponding summary statistics are presented in Table B.7 in appendix. These changes are based on the sum over all crops produced (expressed in tonnes). Although it is not particularly meaningful to sum different crops, we do so for the following reasons: (1) presenting the distributions of changes for individual crops could be misleading, since there are cases where baseline zero sales/purchases turn into positive sales/purchases under the different scenarios, whose change is therefore not defined (these switching cases are the focus of the next section); this is much less of a problem when one focuses on all crops jointly; (2) although production, consumption, sales and purchases of the sum of all crops is problematic in terms of economic interpretation, the changes in these indicators are still useful, including in terms of material balances.

Figure 28: The distributions of changes in farm-household level total consumption, purchased consumption, production and sales (% change relative to the baseline)

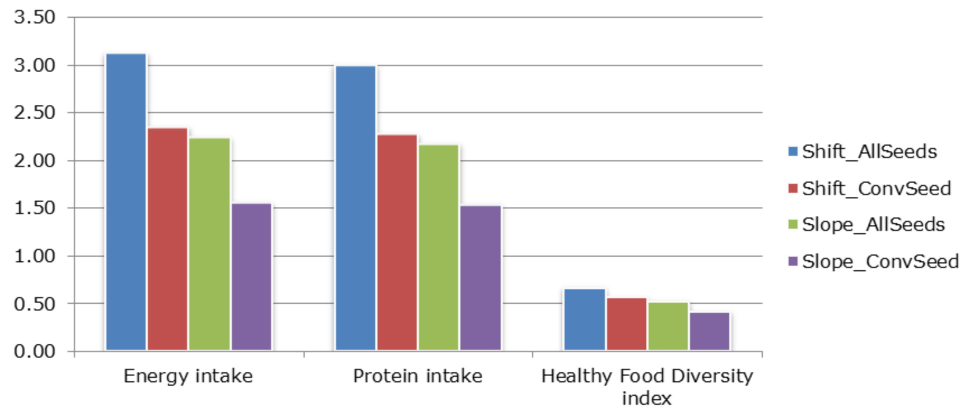


NB: The following buyer/seller switching cases are considered as no change in the corresponding graphs:
for purchases, one farm household switches from zero to positive purchases in all four scenarios;
for sales, five farm households switch from zero to positive sales in one, two or all scenarios.

The mean change in total consumption of the affected farm households ranges from 3.2% to 4.1% (Table B.7). Figure 28 shows the impacts under different scenarios. For example, for changes in total consumption, total production and total sales, any given cumulative share of farm households shows the largest change under the Shift_AllSeeds scenario (i.e. the corresponding distributions are the bottommost ones) and the lowest change under the Slope_ConvSeed scenario (corresponding to the topmost distributions). In the case of purchased consumption, for a given cumulative percentage of farm households, the largest positive change (or lowest negative change) is obtained under the Shift_AllSeeds scenario, and vice versa for the Slope_ConvSeed scenario. This again implies that the largest purchasing impact occurs under the Shift_AllSeeds, and the lowest under the Slope_ConvSeed) scenario.

Finally, the effects of the simulated scenarios on nutrition indicators for the whole country are presented in Figure 29. To quantify the nutrition security impacts, we use the standard indicators of energy intake, protein intake and Healthy Food Diversity Index (HDFI), the details of which can be found in Louhichi et al. (2019). These food and nutrition security measures increase, on average across all four ACC scenarios, by 2.32%, 2.25% and 0.54%, respectively. Thus, as expected, the ACC policies are assessed to lead to an improvement in nutrition and protein intake, and also to a marginal increase in the health value (when differentiating between healthy and unhealthy food categories) of goods consumed.

Figure 29: Change in nutrition indicators (% change relative to the baseline)



6.4 Market participation decision effects

An increase in production of the targeted crops will have an impact on market participation decisions and shift a farm household's status from net buyer or self-sufficient to net seller, and vice versa.

Table 31 shows that such status-switching cases (with rather significant change) occur basically only in markets for the ACC targeted cereals, or related markets. On average across all scenarios, 5.8%, 2.7%, 1.3% and 1.5% of farm households become net sellers (i.e. their baseline zero sales become positive) for wheat, teff, maize and barley, respectively. Hence, increased production of these crops not only helps to make certain farm households self-sufficient, it also leads to higher market participation by farm households who are now able to offer their surplus production in the market, boosting their incomes.

Similarly, on average across all four scenarios, 5.1%, 2.5%, 1.2% and 1.1% of farm households become self-sufficient or net sellers (i.e. their baseline positive purchases are nullified under the ACC scenarios) for wheat, teff, maize and barley respectively. On the other hand, on average over all scenarios, between 0.1% and 0.6% of farm households become net buyers of all other crops (except for fruit crops, chat and 'other crops'). That is, higher income now allows certain farm households to also buy other non-targeted crops.

Table 31: Percent of farm households switching their net selling or buying status

	Switching from Positive to Zero					Switching from Zero to Positive				
	S1	S2	S3	S4	*Average*	S1	S2	S3	S4	*Average*
	Sales (% of farm-households)									
Teff	0.07	0.07	0.21	0.14	*0.12*	3.35	3.20	2.21	2.06	*2.70*
Wheat	0.09	0.17	0.34	0.26	*0.21*	7.70	6.59	4.86	3.84	*5.75*
Maize	0.23	0.27	0.27	0.32	*0.27*	2.11	1.42	1.14	0.41	*1.27*
Barley			0.33	0.44	*0.19*	1.88	1.77	1.10	1.10	*1.46*
Sorghum	0.13	0.20	0.13	0.07	*0.13*			0.07	0.07	*0.03*
Millet	0.22	0.22	0.22		*0.16*					
Pulses	0.57	0.52	0.38	0.38	*0.46*	0.10	0.12	0.12	0.10	*0.11*
Oilseeds	0.37	0.37	0.09	0.09	*0.23*			0.09	0.09	*0.05*
Root crops	0.24	0.21	0.17	0.14	*0.19*	0.03	0.03	0.03	0.03	*0.03*
Fruit crops	0.13	0.13	0.07	0.07	*0.10*					
Chat		0.13		0.13	*0.07*					
Coffee	0.26	0.13	0.13	0.04	*0.14*					
Other crops	0.21	0.24	0.07	0.10	*0.15*	0.03	0.03	0.07	0.07	*0.05*
	Purchases (% of farm-households)									
Teff	3.06	2.92	2.14	1.99	*2.53*	0.14	0.14	0.21	0.21	*0.18*
Wheat	6.76	5.90	4.18	3.42	*5.06*		0.17	0.17	0.34	*0.17*
Maize	2.01	1.33	1.05	0.37	*1.19*	0.32	0.37	0.41	0.50	*0.40*
Barley	1.44	1.32	0.77	0.77	*1.08*	0.33	0.33	0.44	0.44	*0.39*
Sorghum						0.39	0.39	0.13	0.07	*0.24*
Millet						0.22		0.22		*0.11*
Pulses	0.02	0.02	0.02	0.02	*0.02*	0.69	0.67	0.52	0.50	*0.60*
Oilseeds						0.28	0.28			*0.14*
Root crops						0.28	0.24	0.14	0.10	*0.19*
Coffee						0.39	0.26	0.22	0.13	*0.25*

NB: S1, S2, S3 and S4 denote, respectively, Shift_AllSeeds, Shift_ConvSeed, Slope_AllSeeds and Slope_ConvSeed scenarios. Zero percentages are not shown. Source: model results.

7 Conclusion and discussions

This report presents the results of a comprehensive analysis aiming to assess the impact of scaling up the ACC initiative on smallholders' performance in Ethiopia, using the farm household model FSSIM-Dev. The ACC initiative was introduced by the Ethiopian Government under GTP I as a mechanism to integrate the Agricultural Transformation Agenda interventions along specific value chains for a limited number of priority (or high-value) commodities, across the four major agricultural regions of the country: Amhara, Oromia, SNNP and Tigray. It aims to enhance the commercial opportunities for smallholder farmers, through expanding the quantity and quality of three interrelated agricultural inputs - chemical fertilizer, improved seeds, and extension and advisory services - and facilitating market linkages on the output side of smallholder farming 'business'.

The FSSIM-Dev model was used to simulate the effect of this initiative on a representative sample of 2,886 individual farm households from the 2013/14 Ethiopia Socioeconomic Survey. More specifically, we assessed several scenarios for scaling up, to the respective regions of Ethiopia, the productivity performance as achieved by the 'model farmers' in the areas (clusters) covered by the ACC initiative.

From a policy perspective, the main finding of this impact assessment is that introduction of the ACC initiative throughout the main agricultural regions of Ethiopia would lead to the following.

(i) An increase in production of the main commodities, ranging between 1.8% and 62.6% depending on scenario, region and commodity. This increase is driven by the rise in land productivity, rather than area expansion (through bringing fallow land into cultivation) and/or area reallocation. The average country-level production increases across all considered ACC scenarios for wheat, teff, maize and barley were found to be 29.6%, 21.1%, 12.8% and 12.6%, respectively.

(ii) An improvement in both gross and net farm incomes at different levels, from the individual farm household up to regional and national levels. The average increase in gross income, across all scenarios at the country level, is assessed to be around 14%. Regions most positively affected are Amhara and Oromia, namely because in these regions improved productivity shocks were observed for all four targeted crops (maize, wheat, teff and barley). The average increase in gross income for all farms ranges from 6.0% to 12.8%, depending on the scenario considered. The largest change in income is experienced by farms specializing in field crops (which is not surprising as the ACC targeted crops considered are field crops), and in medium-large farms (i.e. farms with economic size > ETB 9,000), given their high land productivity in comparison to small and subsistence farms.

(iii) A rise in both food and non-food consumption, driven by the increase in production and income. Countrywide total consumption of wheat, maize, teff and barley increases, on average across all scenarios, by 3.2%, 3.0%, 2.1% and 2.2%, respectively. This also leads to an improvement in nutritional indicators such as energy intake, protein intake and Healthy Food Diversity Index (HDFI) of 2.32%, 2.25% and 0.54%, respectively.

(iv) A positive impact on market participation decisions, manifested by a shift in farm households' status from net buyer or self-sufficient to net seller. On average across all scenarios, 5.8%, 2.7%, 1.3% and 1.5% of farm households become net sellers of wheat, teff, maize and barley, respectively.

(v) Finally, a reduction of 2.1% in the extreme poverty gap throughout the country, while corresponding region-specific average poverty effects in Amhara, Oromia, SNNP and Tigray are found to be, respectively, -3.1%, -2.6%, -0.5% and -1.7%. The extreme poverty gap is measured as the difference between farm household income per household unit and the extreme poverty line of USD 1.90 equivalent per person per day (ETB 55).

These findings confirm the relatively positive effects of the ACC initiative in increasing staple crop productivity and production, and enhancing farm performance and livelihood. However, as pointed out by Dercon and Gollin (2019), 'while further productivity growth for staple food crops will continue to be needed to keep urban food prices in check, staple food productivity increases will not in themselves be sufficient to create transformation' (p. 460). In their 'forward looking' conclusions, the authors argue that, as boosting productivity of staple crops becomes harder to achieve over time due to increasing costs of intensification, a new strategy of transformation within agriculture will be needed: transformation from low-value production to higher value production. That is, it is expected that growth in urban areas will shift consumer demand from staple foods and relatively unprocessed agricultural goods to processed and prepared foods, as more affluent consumers would put greater value on such food characteristics as convenience of cooking and preparation, food and nutrition quality, food safety, dietary diversity, and standardization of food types. These high-value products, such as animal products, fruits and vegetables, and processed foods, all require more sophisticated value chains than those of staple foods. However, the authors recognize that 'the importance of staple food crops will not diminish immediately; these crops are simply too important to rural livelihoods and to the consumption needs of the rural poor' (p. 462).

Our findings, however, need to be considered with some caution, on account of the model's assumptions. Firstly, all farms in the four regions studied are assumed to adopt the ACC package and to perform like the 'model farmers'. This is a strong assumption, given the low level of technology adoption in sub-Saharan African countries, which may lead to an overestimation of the simulated impacts. Secondly, due to data limitations neither the additional operational costs induced by the ACC initiative nor the administrative costs related to its implementation are taken into account (i.e. only yield effects are simulated). This also may lead to an overestimation of the ACC impacts. Thirdly, output market prices are assumed to be exogenously given. This implies that market feedback (output price changes) is not taken into account in the model. Although in developing economies in general, and in certain parts of Ethiopia in particular, high transaction costs tend to isolate the various local markets from each other and thus prevent price transmission, price effects could be important when production change is quite high, as is the case here. A fourth potential caveat to our analysis is that we assume a fixed farm structure, implying that land extension in response to the introduction of the ACC initiative is not captured by the model. This may lead to an underestimation of the simulated impacts, mainly for farms without fallow land in the baseline. Fifth, the 2013/2014 Ethiopian Socioeconomic Survey includes only small to medium farms; large commercial farms are underrepresented in the database. This is, however, not a major drawback, given that the ACC initiative targets only smallholder farms. Finally, the model considers unlimited access to hired labour at prevailing wages. However, if labour demand is highly concentrated in certain periods of the year, this may well be a limiting factor. A careful analysis of each of these limitations is, therefore, needed when analysing the simulation results.

Despite these limitations, the simulation results presented here can be useful to policymakers currently developing programmes and policies to enhance productivity and sustainability of the farming sector in sub-Saharan African countries. However, as pointed out by Nowicki et al. (2007, p. 34), 'the reader is reminded that no scenario study can claim to present what *will* happen, but merely can portray what *may* happen. What is important afterwards is that these eventualities are debated and that the necessary choices concerning the future of agriculture and the rural world are as fully informed as possible'.

Beyond analysing the effects of selected policy measures, this report aimed to highlight the potential of this kind of modelling approach for making finer policy analyses and for providing policymakers with useful insights into how and where policy measures may be expected to be most effective.

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List of figures

List of tables

Appendix A

Table A.1: Main variables utilized as input for FSSIM-Dev model, based on LSMS-ISA 2013/14 data

Variable	Variable description	Cleaning and data preparation process applied
Household ID	Household ID	Households with no crop activity are eliminated
Field number	Combined parcel ID and field number	Non-agricultural parcels (e.g. plot for housing) are eliminated
Crop (19 crop categories)	Crop (85 distinct crops, many of them occurring only a few times)	Crop categories are selected and crops are classified into FSSIM-Dev crop categories; see Table A.2 for details
Technique	Improved vs conventional seed X irrigated/non-irrigated plot	Improved seed (Y/N) by crop and plot, and irrigated (Y/N) by plot, resulting in 4 techniques (conventional irrigated, conventional rainfed, improved seed irrigated, improved seed rainfed)
Weight	Sampling weight	Sampling weight as provided (for national representativeness)
Area	Area (ha)	Field area planted. 3 types of area measurements have been used. Preference has been given to type of measurement in this order: (1) rope and compass, (2) GPS, (3) farmer reported area. Mismatches between different measurement methods have been checked and most plausible values identified. Missing area has been reconstructed based on median yield and harvested production. Outliers in area have not been adjusted.
Yield	Harvested amount (kg)/Area (ha) or crop-cut yield	3 types of production calculations have been used: (1) harvested amount in kg, as estimated by the farmer; (2) harvested amount in local unit as reported by farmer, converted into kg using LSMS conversion rates, (3) crop-cut yields (dry weight) (4,163 observations). These harvest estimations are divided by area to obtain yields. Yield based on (1) are preferably used, replaced by (2) or (3) in event that yield based on (1) was identified as outliers, while (2) or (3) were not considered outliers. The resulting yields are winsorized at 3% and ad hoc maximum values are imposed to exclude implausible values. Missing values are replaced by median crop yields (*)[21] and corresponding production quantity is derived from median yield and area.
Output price	Value (ETB)/ quantity (kg) of production sold	Farm-specific price. Outliers and missing values are replaced by median price by crop and village (or higher level if small number of observations)
Seed quantity	Seed quantity (kg) / area (ha)	Outliers have been detected (Tukey method by crop) and replaced by median. Where seed quantity is missing, this has been replaced by median (by crop and region).
Seed price	Value (ETB) /quantity (kg) of purchased seeds	Median price by village (or higher level)
Urea quantity	Urea quantity (kg) / area (ha)	Outliers have been detected (Tukey method by crop) and replaced by median. Where urea is reported to be used, but quantity missing, this has been replaced by median (by crop and region).
Urea price	Value (ETB) / quantity (kg) of purchased urea	Median price by village (or higher level)
DAP quantity	DAP quantity (kg) / area (ha)	Outliers have been detected (Tukey method by crop) and replaced by median. Where DAP is reported to be used, but quantity missing, this has been replaced by median (by crop and region).
DAP price	Value (ETB) / quantity (kg) of purchased DAP	Median price by village (or higher level)
Nitrogen quantity	N quantity (kg) / area (ha)	Quantity of N used, derived from Urea or DAP: N quantity = (0.18 x DAP quantity) + (0.46 x urea quantity)
Nitrogen price	Value (ETB) / quantity (kg) of N	Nitrogen price is calculated as (value of DAP used + value of Urea used) / (quantity of Nitrogen)
Labour availability post-	Total labour used (days) / area (ha)	Total number of days (7 hours/day) of hired, exchange and household labour used (including male, female and child labour, the latter

[21] Outliers and missing values have been indicated by median values. When indicated by (*), this means that first the median value is taken at the lowest level, with at least 15 non-missing and non-outlier observations. This means that, when possible, the median is taken at village level. In the event of less than 15 observations, the median at *woreda*, zone, regional or national level is taken.

planting		valued at 0.5 day) per area in post-planting season. Outliers have been detected (Tukey method) for each labour category separately, as well as for total labour used, and have been replaced by median.
Labour availability post-harvest	Total labour used (days) / area (ha)	Total number of days (7 hours/day) of hired, exchange and household labour used (including male, female and child labour, the latter valued at 0.5 day) per area in post-harvest season. Outliers have been detected (Tukey method) for each labour category separately, as well as for total labour used, and have been replaced by median.
Price of hired labour post-planting	Wage (ETB/day)	Median price of female and male labour per day at village level during post-planting season, weighted by the average share of female and male labour used for each crop during that season
Price of hired labour post-harvest	Wage (ETB/day)	Median price of female and male labour per day at village level during post-harvest season, weighted by the average share of female and male labour used for each crop during that season
Capital cost	Total asset depreciation (ETB) / area (ha)	Yearly depreciation of households' agricultural assets (sickle, axe, pickaxe, traditional plough, modern plough) per area, valued at community level prices. Depreciation period is set to 5 years for sickle, axe and pickaxe, and to 15 years for traditional or modern plough.
Land price	Rental price of land (ETB) / area (ha)	Median land rental price, by region and soil quality
Standard deviation of land price	Standard deviation (ETB/ha)	Standard deviation in land rental price, by region and soil quality
Farm specialization	Share of crop groups in total output (3 categories)	Crop specialization: 1) Field crops (> 80% of total output in cereals, tubers, pulses, oilseeds); 2) Permanent crops (> 50% of total output in fruits or cash crops); 3) Mixed (other)
Economic size	Total value of production (3 categories)	Total production value over all crops: 1) < ETB 4,000; 2) ETB 4,000-9,000; 3) > ETB 9,000
Market orientation	Share of total output that is marketed (3 categories)	Share of total output that is marketed: 1) Not market oriented (0% marketed); 2) Low market orientation (< 10% marketed); 3) Market oriented (> 10% marketed)
Farm Type	Economic size x market orientation (9 categories)	Combines economic size and market orientation, resulting in 9 farm types. Depending on the number of observations per farm type in each region, certain types have been merged to assure at least 20 observations within each farm type.

Table A.2: Selection and classification of crops into FSSIM-Dev crop categories

The selection of FSSIM-Dev crops is based on each crop's contribution to total production value in each region of the country. All crops making up at least 5% of production value in one of the regions are maintained as a separate category. Other crops are classified by crop type. Five crops (amboshika, comtatie, kazmir, roman and timiz kimem) could not be assigned to any of the categories and were not included. This covers 21 fields out of a total of 28,617 fields. Fields classified as grassland/forest are also not included in this version of the model.

FSSIM-Dev code	Crop category	Crops from LSMS-ISA survey included
BARL	Barley	Barley
MAZE	Maize	Maize
MILE	Millet	Millet
SORG	Sorghum	Sorghum
TEFF	Teff	Teff
WHEA	Wheat	Wheat
SESA	Sesame	Sesame
CHAT	Chat	Chat
COFF	Coffee	Coffee
ENSE	Enset	Enset
FRUO	Other fruits	Cactus, apples, bananas, grapes, lemons, mandarins, mangos, oranges, papaya, pineapples, citron, guava, peach, gishita, watermelon, avocados, strawberry, other fruits
OSPI	Other spices	Mego, savory, black cumin, black pepper, cardamom, chilies, cinnamon, fenugreek, ginger, red pepper, turmeric, coriander, sacred basil, rue, other spices
PULP	Other pulses	Chickpeas, haricot beans, horse beans, lentils, field peas, vetch, gibto, soya beans, white lumen, other pulses
OILO	Other oilseeds	Castor beans, cotton seed, linseed, ground nuts, nueg, rapeseed, sunflower, other oilseeds
CERO	Other cereals	Oats, rice, other cereals
OCAS	Other cash crops	Cotton, gesho, sugar cane, tea, tobacco, other cash crops
OVEG	Other vegetables	Fennel, beetroot, cabbage, carrot, cauliflower, garlic, kale, lettuce, onion, green pepper, potatoes, pumpkins, sweet potato, tomatoes, godere, mustard, feto, spinach, green beans, other vegetables
OTUB	Other tubers	Cassava, goye, yam, other root crops
Not included	Other crops	Amboshika, comtatie, kazmir, roman, timiz kimem
Not included	Grazing land/forest	Grazing land, temporary grassland, forest land/eucalyptus tree, other land

Table A.3: Own-price elasticities of supply by crop, used as exogenous supply elasticities in the calibration step of FSSIM-Dev

Crop	Elasticity used in FSSIM-Dev	Source	Original estimates from literature	Remarks
BARL	0.15	Abrar et al. (2003)	-0.02, 0.13	Estimate for Northern and Central zone respectively. Negative estimate for Northern zone not considered because of implausible value)
MAZE	0.5	Abrar et al. (2003)	0.08, 0.62, 0.57	Based on estimates for Northern, Central and Southern zone (taking into account concentration of production mostly in C and S region)
		Alemu et al. (2003)	0.51, 0.38	Long- and short-run supply, national level
		Zheng et al. (2015)	0.5	Supply estimate assumed to be 0.5, based on SSA range (0.157 to 0.68)
MILE	0.2	No estimate found.	-	Same estimate as sorghum has been taken
SORG	0.2	Abrar et al. (2003)	0.20	Estimated for Northern zone only
		Alemu et al. (2003)	0.43, 0.09	Long- and short-run supply, national level
TEFF	0.4	Abrar et al. (2003)	0.06, 0.44, 0.35	Based on estimates for Northern, Central and Southern zone (taking into account concentration of production mostly in C region)
		Alemu et al. (2003)	0.28, 0.14	Long- and short-run supply, national level
WHEA	0.25	Abrar et al. (2003)	0.2, 0.24	Estimated for Northern and Central zone
		Alemu et al. (2003)	0.28, 0.15	Long- and short-run supply, national level
SESA	0.15	Abrar et al. (2003)	0.08, 0.12, 0.17	Estimates for other crops in Northern, Central and Southern zone
CHAT	0.35	Abrar et al. (2003)	0.35	Estimate for tree crops in Central zone
		Abrar et al. (2003)	1.08	Estimate for chat in Southern zone (estimate not considered because implausibly high)
COFF	0.35	Abrar et al. (2003)	0.35	Estimate for Southern zone
ENSE	0.15	Abrar et al. (2003)	0.08, 0.12, 0.17	Estimates for other crops in Northern, Central and Southern zone
FRUO	0.35	Abrar et al. (2003)	0.35	Estimate for tree crops in Central zone
OSPI	0.15	Abrar et al. (2003)	0.08, 0.12, 0.17	Estimates for other crops in Northern, Central and Southern zone
PULO	0.15	Abrar et al. (2003)	0.08, 0.12, 0.17	Estimates for other crops in Northern, Central and Southern zone
OILO	0.15	Abrar et al. (2003)	0.08, 0.12, 0.17	Estimates for other crops in Northern, Central and Southern zone
CERO	0.15	Abrar et al. (2003)	0.08, 0.12, 0.17	Estimates for other crops in Northern, Central and Southern zone
OCAS	0.35	Abrar et al. (2003)	0.35	Estimate for tree crops in Central zone
OVEG	0.15	Abrar et al. (2003)	0.08, 0.12, 0.17	Estimates for other crops in Northern, Central and Southern zone
OTUB	0.15	Abrar et al. (2003)	0.08, 0.12, 0.17	Estimates for other crops in Northern, Central and Southern zone

Table A.4: Income elasticities used in FSSIM-Dev

Consumption category	VDS (2019)	USDA 2005	FSSIM-Dev
Barley	1.432	0.622	0.631
Maize	1.561	0.622	0.688
Millet	1.432	0.622	0.631
Sorghum	1.432	0.622	0.631
Teff	1.045	0.622	0.461
Wheat	1.561	0.622	0.688
Chickpeas	0.971		0.971
Haricot beans	0.971		0.971
Horse beans	0.971		0.971
Lentils	0.971		0.971
Field peas	0.971		0.971
Linseed	0.971		0.971
Nuegs	0.971		0.971
Banana	1.206	0.684	0.945
Onion	0.875	0.684	0.779
Potatoes	1.014	0.684	0.849
Kocho	1.248	0.684	0.966
Bula	1.248	0.684	0.966
Chat	0.614		0.614
Coffee	0.874		0.874
Meat	1.006	0.820	0.913
Milk	1.787	0.848	0.848
Cheese	1.787	0.848	0.848
Sugar		0.827	0.827
Salt		0.827	0.827
Eggs		0.827	0.827
Beverage & tobacco		1.488	1.488
Breads, cereals		0.622	0.622
Meal away from home		0.820	0.820
Fish		0.713	0.713
Dairy		0.848	0.848
Fats & oils		0.631	0.631
Fruits & vegetables		0.684	0.684
Other foods		2.275	2.275
Clothing & footwear		0.968	0.968
Rent & fuel		1.081	1.081
House operations		1.058	1.058
Medical care		3.275	3.275
Education		0.935	0.935
Transport & communication		1.270	1.270
Recreation		5.406	5.406

NB: VDS (2019) refers to the study by Vigani, Dudu and Solani-Hermosilla (2019), while USDA 2005 refers to the income elasticities for food subcategories and broad consumption categories for 2005 reported in International Food Consumption Patterns published by the United States Department of Agriculture (https://www.ers.usda.gov/data-products/international-food-consumption-patterns.aspx). Income elasticities used in FSSIM-Dev employ both sources. When there are two estimates for a category, we take the average of both, except for cereals. We find the expenditure elasticities for cereals reported by VDS (2019) somewhat high (given that these are staple/basic food for which economic theory predicts income elasticity of less than one), hence we have adjusted them such that their average coincides with corresponding USDA income elasticity of 0.622. That is, for cereals we obtain the corresponding elasticities as: Elasticity(FSSIM-Dev) = Elasticity(VDS) * [Elasticity(USDA)/Average(Elasticities(VDS))] .

Appendix B

Table B.1: Changes in gross income per ha (% of baseline)

	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed
		Ethiopia		
Teff	32.67	31.86	22.79	22.03
Wheat	43.01	38.86	35.55	31.57
Maize	34.07	10.61	24.83	3.20
Barley	22.44	21.89	13.20	12.99
Sorghum	-0.06	-0.05	0.00	0.02
Millet	0.05	0.05	0.00	0.00
Pulses	0.09	0.09	0.07	0.07
Oilseeds	0.25	0.15	0.15	0.06
Root crops	0.24	0.24	0.00	0.00
Fruit crops	0.12	0.13	-0.01	0.00
Chat	0.18	-0.01	0.27	0.06
Coffee	-0.16	-0.20	-0.13	-0.17
Enset	0.03	0.01	0.00	0.00
Other crops	0.01	0.00	0.00	-0.01
		Amhara		
Teff	44.80	43.39	26.06	24.75
Wheat	53.09	48.20	32.01	27.61
Maize	58.32	16.17	47.14	5.34
Barley	15.04	14.95	5.13	5.12
		Oromia		
Teff	30.12	29.70	23.55	23.16
Wheat	34.44	33.22	30.77	29.54
Maize	28.84	10.47	17.74	2.87
Barley	32.52	31.60	20.77	20.41
		SNNP		
Teff	0.00	0.00	0.00	0.00
Wheat	94.64	67.81	86.39	60.45
Maize	-0.01	0.00	-0.01	0.00
Barley	-0.01	-0.01	-0.01	-0.01
		Tigray		
Teff	60.18	55.96	51.44	47.22
Wheat	79.61	56.73	66.09	44.11
Maize	0.57	0.57	0.44	0.44
Barley	-0.03	-0.03	-0.03	-0.03

Table B.2: Changes in net income per ha (% of baseline)

	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed
	Ethiopia			
Teff	8.46	8.25	5.95	5.75
Wheat	18.98	17.14	15.71	13.95
Maize	4.63	1.30	3.42	0.36
Barley	4.56	4.45	2.67	2.63
Sorghum	0.11	0.09	0.04	0.02
Millet	0.01	0.01	0.00	0.00
Pulses	0.07	0.05	0.07	0.05
Oilseeds	0.48	0.32	0.16	0.01
Root crops	0.22	0.22	0.01	0.01
Fruit crops	0.18	0.19	0.01	0.01
Chat	0.75	0.38	0.49	0.20
Coffee	0.16	0.12	0.13	0.09
Enset	0.06	0.04	0.01	0.00
Other crops	1.43	1.38	0.04	-0.01
	Amhara			
Teff	15.33	14.85	9.05	8.60
Wheat	24.59	22.30	14.88	12.83
Maize	34.88	9.56	28.29	3.17
Barley	2.74	2.73	0.88	0.89
	Oromia			
Teff	6.39	6.30	4.99	4.91
Wheat	15.74	15.18	14.06	13.50
Maize	1.94	0.57	1.18	0.08
Barley	7.47	7.26	4.79	4.70
	SNNP			
Teff	0.00	0.00	0.00	0.00
Wheat	33.30	23.88	30.39	21.28
Maize	0.00	0.01	0.00	0.00
Barley	0.02	0.02	0.02	0.02
	Tigray			
Teff	19.64	18.28	16.79	15.43
Wheat	21.99	15.67	18.26	12.18
Maize	0.00	0.00	0.00	0.00
Barley	0.02	0.02	0.02	0.02

Table B.3: Changes in total consumption (% of baseline)

	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed
	Ethiopia			
Teff	2.64	2.07	2.05	1.54
Wheat	3.83	3.20	3.09	2.52
Maize	3.99	2.87	3.09	2.09
Barley	2.52	2.37	1.96	1.83
Sorghum	1.99	1.61	1.02	0.65
Millet	2.29	0.97	1.96	0.66
Pulses	4.59	3.56	3.31	2.34
Oilseeds	0.52	0.42	0.49	0.41
Root crops	5.78	3.96	3.80	2.54
Fruit crops	0.80	0.71	0.65	0.58
Chat	1.06	0.99	0.86	0.81
Coffee	6.69	5.43	4.63	3.49
	Amhara			
Teff	3.63	2.61	2.47	1.47
Wheat	5.95	3.89	4.37	2.37
Maize	6.51	3.33	5.53	2.41
Barley	1.62	1.45	0.65	0.51
Sorghum	2.09	1.95	0.56	0.44
Millet	3.48	1.40	3.03	0.97
Pulses	7.53	5.25	4.75	2.53
Oilseeds	0.85	0.67	0.89	0.71
Root crops	6.44	3.65	4.96	2.22
Fruit crops	0.22	0.20	0.09	0.07
Chat	0.23	0.22	0.03	0.03
Coffee	13.44	9.79	7.61	4.05
	Oromia			
Teff	2.70	2.22	2.20	1.80
Wheat	4.07	3.79	3.37	3.17
Maize	4.50	3.64	3.15	2.48
Barley	3.57	3.44	2.98	2.86
Sorghum	2.24	1.52	1.62	0.91
Millet	0.44	0.36	0.25	0.18
Pulses	4.33	3.71	3.40	2.89
Oilseeds	0.37	0.33	0.31	0.28
Root crops	8.76	6.48	5.04	4.09
Fruit crops	1.65	1.50	1.36	1.25
Chat	1.51	1.41	1.23	1.16
Coffee	7.77	6.76	5.60	4.77
	SNNP			
Teff	0.45	0.30	0.44	0.29
Wheat	1.53	1.12	1.40	1.00
Maize	2.18	1.47	2.01	1.33
Barley	0.37	0.27	0.29	0.21
Sorghum	1.00	0.71	0.88	0.60
Millet	-0.02	0.04	0.01	-0.10
Pulses	1.83	1.44	1.70	1.31
Oilseeds	0.09	0.01	0.04	0.00
Root crops	1.05	0.75	1.00	0.70
Fruit crops	0.21	0.16	0.15	0.13
Chat	0.06	0.05	0.05	0.05
Coffee	2.51	1.97	2.15	1.65
	Tigray			
Teff	2.33	2.05	2.14	1.87
Wheat	2.75	2.17	2.28	1.71
Maize	7.13	6.70	5.64	5.21
Barley	1.55	1.21	1.38	1.06
Sorghum	2.70	2.59	0.83	0.72
Millet	0.18	0.17	0.16	0.15
Pulses	2.97	2.60	1.88	1.52
Oilseeds	0.60	0.45	0.53	0.38
Root crops	2.43	1.85	2.10	1.52
Fruit crops	0.20	0.14	0.16	0.10
Chat	0.01	0.01	0.00	0.00
Coffee	5.35	3.96	4.60	3.30

Table B.4: Changes in purchased consumption (% of baseline)

	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed
	Ethiopia			
Teff	-9.27	-9.34	-6.26	-6.31
Wheat	-9.00	-8.25	-6.72	-5.97
Maize	-2.68	-1.10	0.03	1.11
Barley	-6.38	-6.23	-3.58	-3.55
Sorghum	2.56	2.10	1.22	0.78
Millet	3.21	1.28	2.78	0.89
Pulses	4.88	3.62	3.58	2.39
Oilseeds	0.66	0.55	0.40	0.29
Root crops	4.90	3.58	3.90	2.63
Fruit crops	0.88	0.80	0.72	0.66
Chat	1.05	0.89	0.76	0.66
Coffee	8.89	7.23	6.20	4.67
	Amhara			
Teff	-15.11	-15.39	-7.13	-7.41
Wheat	-17.21	-17.01	-7.18	-6.93
Maize	-15.68	-8.59	-7.46	-0.92
Barley	-3.23	-3.35	-1.04	-1.27
Sorghum	3.32	2.99	0.89	0.60
Millet	5.89	2.17	5.18	1.54
Pulses	8.55	5.63	5.70	2.81
Oilseeds	1.14	0.92	0.50	0.29
Root crops	7.89	4.45	6.14	2.75
Fruit crops	0.24	0.22	0.09	0.07
Chat	0.26	0.26	0.04	0.04
Coffee	13.99	10.15	7.88	4.14
	Oromia			
Teff	-8.79	-8.99	-6.49	-6.65
Wheat	-5.65	-5.60	-5.05	-4.98
Maize	-4.26	-1.84	0.41	1.81
Barley	-11.96	-11.45	-7.18	-6.89
Sorghum	2.44	1.69	1.73	1.00
Millet	0.59	0.51	0.36	0.29
Pulses	4.80	3.98	3.67	3.00
Oilseeds	0.46	0.40	0.38	0.33
Root crops	6.05	5.20	4.77	4.01
Fruit crops	1.76	1.63	1.46	1.36
Chat	1.62	1.37	1.19	1.03
Coffee	10.54	9.35	7.83	6.86
	SNNP			
Teff	0.41	0.22	0.40	0.20
Wheat	-11.24	-10.16	-9.20	-8.12
Maize	0.76	0.55	0.63	0.45
Barley	0.54	0.40	0.42	0.30
Sorghum	0.97	0.79	0.85	0.68
Millet	0.00	0.00	0.00	0.00
Pulses	1.68	1.28	1.65	1.26
Oilseeds	0.09	0.01	0.04	0.00
Root crops	1.09	0.77	1.04	0.72
Fruit crops	0.25	0.19	0.18	0.15
Chat	0.05	0.05	0.05	0.05
Coffee	3.49	2.66	3.04	2.27
	Tigray			
Teff	-14.91	-13.79	-13.70	-12.56
Wheat	-16.22	-11.06	-13.74	-8.83
Maize	9.68	9.10	7.75	7.16
Barley	1.89	1.35	1.67	1.14
Sorghum	4.79	4.55	1.03	0.79
Millet	0.16	0.15	0.13	0.12
Pulses	3.43	2.97	2.05	1.61
Oilseeds	0.51	0.33	0.43	0.26
Root crops	2.45	1.86	2.11	1.53
Fruit crops	0.22	0.15	0.17	0.11
Chat	0.00	0.00	0.00	0.00
Coffee	5.35	3.96	4.61	3.30

Table B.5: Changes in own-produced consumption (% of baseline)

	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed
		Ethiopia		
Teff	12.18	11.22	8.71	7.82
Wheat	15.72	13.80	12.17	10.37
Maize	11.76	7.50	6.66	3.22
Barley	10.62	10.19	6.99	6.72
Sorghum	1.46	1.15	0.84	0.54
Millet	1.55	0.72	1.30	0.47
Pulses	3.77	3.40	2.54	2.21
Oilseeds	0.21	0.17	0.69	0.64
Root crops	12.61	6.90	3.07	1.85
Fruit crops	0.24	0.15	0.19	0.10
Chat	1.09	1.26	1.11	1.21
Coffee	2.55	2.05	1.69	1.25
		Amhara		
Teff	14.49	13.04	8.04	6.62
Wheat	18.82	15.50	10.79	7.53
Maize	14.78	7.78	10.38	3.65
Barley	5.95	5.74	2.16	2.09
Sorghum	1.40	1.37	0.37	0.34
Millet	2.09	0.95	1.78	0.65
Pulses	5.06	4.35	2.46	1.84
Oilseeds	0.20	0.09	1.78	1.67
Root crops	1.36	0.86	0.85	0.35
Fruit crops	-0.01	-0.01	0.01	0.01
Chat	-0.04	-0.04	0.00	0.00
Coffee	6.52	5.33	4.27	2.91
		Oromia		
Teff	10.93	10.25	8.43	7.85
Wheat	11.78	11.25	10.04	9.63
Maize	13.67	9.38	6.02	3.18
Barley	14.97	14.37	10.43	10.02
Sorghum	2.03	1.33	1.49	0.82
Millet	0.22	0.15	0.08	0.01
Pulses	3.32	3.13	2.80	2.63
Oilseeds	0.21	0.20	0.19	0.18
Root crops	35.10	18.97	7.63	4.82
Fruit crops	0.70	0.43	0.55	0.27
Chat	1.28	1.49	1.31	1.43
Coffee	3.37	2.66	2.07	1.46
		SNNP		
Teff	0.51	0.44	0.51	0.45
Wheat	24.64	21.54	20.56	17.49
Maize	6.20	4.09	5.95	3.83
Barley	0.09	0.06	0.08	0.07
Sorghum	1.09	0.50	0.97	0.43
Millet	-0.10	0.13	0.04	-0.43
Pulses	2.94	2.59	2.00	1.69
Oilseeds	0.00	0.00	0.00	0.00
Root crops	0.39	0.39	0.33	0.33
Fruit crops	0.01	0.01	0.01	0.01
Chat	0.12	0.13	0.08	0.09
Coffee	1.35	1.14	1.08	0.90
		Tigray		
Teff	28.32	25.92	26.02	23.63
Wheat	28.83	20.35	24.29	16.20
Maize	4.71	4.42	3.64	3.35
Barley	1.10	1.04	0.99	0.95
Sorghum	0.69	0.70	0.64	0.64
Millet	0.21	0.19	0.21	0.19
Pulses	1.54	1.43	1.33	1.22
Oilseeds	1.16	1.16	1.13	1.13
Root crops	0.00	0.00	0.00	0.00
Fruit crops	0.00	0.00	0.00	0.00
Chat	0.07	0.07	0.04	0.04
Coffee	0.00	0.00	0.00	0.00

Table B.6: Changes in sales (% of baseline)

	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed
	Ethiopia			
Teff	38.39	38.00	28.21	27.81
Wheat	47.17	42.84	38.93	34.73
Maize	32.21	9.06	22.79	1.57
Barley	27.54	27.12	12.15	12.18
Sorghum	-2.08	-1.66	-1.10	-0.69
Millet	-1.75	-0.82	-1.46	-0.53
Pulses	-2.47	-2.13	-1.71	-1.40
Oilseeds	-0.19	-0.09	-0.13	-0.03
Root crops	-4.07	-2.24	-0.99	-0.60
Fruit crops	-0.10	-0.04	-0.07	-0.02
Chat	-1.30	-1.28	-0.95	-0.93
Coffee	-1.04	-0.88	-0.72	-0.58
	Amhara			
Teff	52.24	51.23	35.30	34.37
Wheat	60.78	55.95	38.54	34.26
Maize	72.53	20.24	56.69	5.25
Barley	14.76	14.80	3.56	3.57
Sorghum	-1.75	-1.71	-0.33	-0.30
Millet	-2.63	-1.20	-2.22	-0.80
Pulses	-2.99	-2.41	-1.49	-0.95
Oilseeds	-0.42	-0.18	-0.29	-0.05
Root crops	-1.35	-0.87	-0.83	-0.35
Fruit crops	-0.04	-0.04	0.00	0.00
Chat	-0.09	-0.08	-0.01	0.00
Coffee	-2.47	-2.07	-1.44	-0.98
	Oromia			
Teff	33.79	34.00	27.02	27.15
Wheat	37.42	36.13	33.04	31.68
Maize	22.43	6.88	13.68	1.01
Barley	51.77	50.69	26.03	26.06
Sorghum	-3.35	-2.24	-2.45	-1.37
Millet	-0.47	-0.32	-0.18	-0.02
Pulses	-2.65	-2.50	-2.26	-2.12
Oilseeds	-0.04	-0.03	-0.03	-0.02
Root crops	-4.92	-2.66	-1.07	-0.67
Fruit crops	-0.13	-0.09	-0.08	-0.04
Chat	-3.73	-3.66	-3.09	-3.02
Coffee	-1.43	-1.21	-0.97	-0.78
	SNNP			
Teff	-0.43	-0.38	-0.44	-0.39
Wheat	104.15	71.31	94.80	63.16
Maize	-7.60	-5.01	-7.27	-4.68
Barley	-0.33	-0.27	-0.31	-0.28
Sorghum	-1.96	-0.90	-1.74	-0.75
Millet	0.08	-0.32	-0.20	0.72
Pulses	0.71	1.09	-0.35	-0.01
Oilseeds	0.00	0.00	0.00	0.00
Root crops	-0.46	-0.46	-0.38	-0.38
Fruit crops	-0.17	-0.03	-0.17	-0.03
Chat	-0.39	-0.39	-0.12	-0.12
Coffee	-0.49	-0.42	-0.39	-0.33
	Tigray			
Teff	78.43	73.05	64.49	59.10
Wheat	178.00	131.65	142.01	97.31
Maize	-4.97	-4.67	-3.87	-3.58
Barley	-1.54	-1.46	-1.39	-1.34
Sorghum	-0.98	-0.93	-0.91	-0.86
Millet	-0.10	-0.09	-0.10	-0.09
Pulses	-1.07	-0.99	-0.88	-0.81
Oilseeds	-0.01	-0.01	-0.01	-0.01
Root crops				
Fruit crops	0.00	0.00	0.00	0.00
Chat	0.00	0.00	0.00	0.00
Coffee				

Table B.7: Summary statistics of farm household level changes in total consumption, purchased consumption, own-produced consumption, and sales of all produced crops, Ethiopia (% of baseline)

	Shift_AllSeeds	Shift_ConvSeed	Slope_AllSeeds	Slope_ConvSeed
	Total consumption change (%)			
Mean (all farm households)	2.24	1.79	1.51	1.10
Median (all farm households)	0.10	0.04	0.00	0.00
Mean (affected farm households)	3.79	3.16	4.12	3.36
Median (affected farm households)	1.69	1.35	1.99	1.48
Standard deviation	5.78	4.74	4.33	3.38
	Purchased consumption change (%)			
Mean (all farm households)	0.29	0.07	0.51	0.27
Median (all farm households)	0.00	0.00	0.00	0.00
Mean (affected farm households)	0.49	0.12	1.39	0.83
Median (affected farm households)	0.01	0.01	0.02	0.02
Standard deviation	15.25	14.21	11.69	10.56
	Own-produced consumption change (%)			
Mean (all farm households)	6.16	5.17	3.80	2.94
Median (all farm households)	0.02	0.00	0.00	0.00
Mean (affected farm households)	11.29	9.95	10.94	9.50
Median (affected farm households)	7.03	5.90	6.64	5.46
Standard deviation	11.01	9.99	8.83	7.75
	Sales change (%)			
Mean (all farm households)	22.17	18.76	14.19	11.12
Median (all farm households)	0.00	0.00	0.00	0.00
Mean (affected farm households)	42.29	37.45	45.08	39.42
Median (affected farm households)	15.66	10.76	15.06	9.44
Standard deviation	307.93	307.15	304.04	303.35

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