Modelling farm-household level impacts of fertilizer subsidy programs on productivity and food security: The case of Ethiopia

Laura Riesgo, Kamel Louhichi, Sergio Gomez y Paloma

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European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS), Edificio Expo. C/ Inca Garcilaso 3, 41092 Seville, Spain

Abstract

Fertilizer subsidy program is one of the most well-known and politically sensitive policies in Sub-Saharan countries. Countries such as Malawi, Nigeria, Ghana and Ethiopia are characterized by large funded fertilizer subsidy programs in recent years. Malawi, Ghana and Nigeria administer a targeted input subsidy program (e.g. fertiliser voucher program), while Ethiopia uses a universal subsidy program where the government imports fertilizer and distributes it among farmers at below-market price through the network of cooperative unions. These two programs, highly discussed in the literature, often raise a debate. This paper aims at contributing to this discussion by assessing the likely impacts of these two fertilizer subsidy programs (flexible and targeted programs) on the productivity and food security of Ethiopian smallholder farmers. A novel farm-household model, FSSIM-Dev (Farm System Simulator for Developing Countries), is used to test both programs as well as to assess their production, consumption and welfare effects on a nationally representative sample of farm households in Ethiopia.

1. Introduction

According to the World Bank's estimates (World Bank, 2015), 78% of the world's extreme poor (i.e. with less than 1.25 USD-equivalent per person and day) were concentrated in rural areas, and most of them were involved in farming. Although poverty continues to decline in many countries, major progress is yet to be made in Sub-Saharan Africa (SSA) rural areas where most of the population is extremely poor (i.e. 52%) and dependent on small holdings (FAO, 2015).

For Ethiopia, agriculture is still of great importance accounting for 42.3% of total GDP in 2014 and 80% of employment (African Development Bank, 2015). Smallholder households are prevalent in agriculture and nearly 55% of smallholders operate on one hectare or less (African Development Bank Group, 2015). Small size of farms, jointly with low input-low output and rainfed farming systems make households very vulnerable to any market or environmental shock (Headey et al., 2013). Thus, rising prices of agricultural inputs cause

difficulties for smallholder farmers to adopt technologies, and soil erosion due to over-cultivation or cultivation of marginal lands cause real constraints for improving agricultural productivity.

Many programs have been initiated by governments and donors in the region to improve agricultural productivity and food security, however with mixed performance to date. Among such efforts, we may mention input subsidy programs, access to irrigation, improved seed varieties and inorganic fertilizers, output price support programs and long run investment programs such as investments in roads, education and agricultural R&D (WB, 2008; Sanchez et al., 2007; Barrett and Carter, 2013).

Fertilizer subsidy program is one of the most well-known and politically sensitive policies. Ethiopia reformed its policy in fertilizer use in 1992 towards a free market. At that date, the Ethiopian government liberalized the existing monopoly on fertilizer importation and distribution (Spielman et al., 2010). Despite the liberalization, the entry of holding companies with strong ties to government limited the competition between the government through the Agricultural Input Supplies Enterprise (AISE), private and holding companies. As a result, only AISE and holding companies accounted for all fertilizer imports and distribution in 2002 (Jayne et al., 2003). In 2007 cooperatives were also involved in fertilizer imports, in order to encourage the participation of farmers' organizations. However, some problems derived from the high fertilizer costs, makes that only the Government intervenes in fertilizers imports since 2009. Thus, through a universal subsidy program the government imports fertilizer and distributes it among farmers at below-market price through the network of cooperative unions. At present, about 90% of the total fertilizer is bought on credit at below-market interest or even at zero interest resulting in an increase in total fertilizer use (Yamano and Arai, 2010). As a result of this policy on universal subsidies, fertilized hectares increased from 2.31 million in 2010 to 8.18 million in 2014.

By contrast, other SSA countries, such as Malawi, Kenya, Nigeria, Ghana, the United Republic of Tanzania and Zambia administer a targeted input subsidy program. Under this program farmers that fulfil a number of prerequisites, such as growing targeted crops (usually staple crops), having small holdings and/or being located in specific areas are eligible and receive a volume of subsidised fertilizer. Some of these targeted fertilizer subsidies are implemented through vouchers such as in Malawi, Kenya or the United Republic of Tanzania. These vouchers allow transferring purchasing power to smallholder farmers either by reducing the price of the input at a price below-market (e.g. United Republic of Tanzania) or by allowing farmers to get a predetermined volume fertilizers at a fixed reduced price (e.g. Malawi).

Both types of fertilizer subsidy programs, highly discussed in the literature, often rise a debate between those who sustain their effectiveness in bringing about an African green revolution (Denning et al., 2009; Javdani, 2012; Sachs, 2012) and those who considers them inefficient given their high, possibly unsustainable costs and inconsistent farm-level impact

and development outcomes (Chibwana et al., 2014; Holden and Lunduka, 2010; Ricker-Gilbert and Jayne, 2011).

This paper aims at contributing to this debate by assessing the likely impacts of two fertilizer subsidy programs (flexible and targeted programs) on the productivity and food security of Ethiopian smallholder farmers. A novel farm-household model, FSSIM-Dev (Farm System Simulator for Developing Countries), is used to test both programs as well as to assess their production, consumption and welfare effects on a nationally representative sample of farm households in Ethiopia.

2. Materials and Methods

The Central Statistical Agency of Ethiopia collects data on Ethiopian agriculture on annual basis through the Agricultural Sample Survey (AgSS). This is an extensive survey that collects data on crop area and production, yields and inputs use from smallholder and commercial farms, considering that approximately 95% of the annual production in Ethiopia is generated by smallholder farms.

We have primary data of five datasets of AgSS from 2010-11 to 2014-15. This survey covers the entire rural parts of the country except the non-sedentary population of 3 zones of Afar and 6 zones in the Somali regions.

Table 1: AgSS sample information, 2010-2015

| Year	Regions	Zones	Enumeration Areas	Households
2010-11	10	66	2 236	41 540
2011-12	10	66	2 273	42 631
2012-13	10	66	2 219	41 210
2013-14	10	66	2 252	40 736
2014-15	10	66	2 187	38 871

Source: AgSS, 2010-2015

We count with information for more than 2,100 enumeration areas, in which around 40,000 agricultural households were interviewed each year. Enumeration areas were selected on the basis of the 2001 cartographic census framework.

Please find below a characterisation of Ethiopian agriculture on the basis of the AgSS datasets for 2010-15.

2.1. Characterization of agriculture

The agriculture in Ethiopia is characterised, as occurs in most SSA countries, by small farms. Figure 1 shows that the average farm size varies among regions, from 1.5 hectares in Oromia

to around 0.5 hectares in Afar. We can observe as well that the average farm size per region is diminishing. The smaller size of the farms the less effective the farmers apply management techniques such as soil erosion control, which is an issue in Ethiopia. Farmers with small farms are more vulnerable to food and income insecurity.
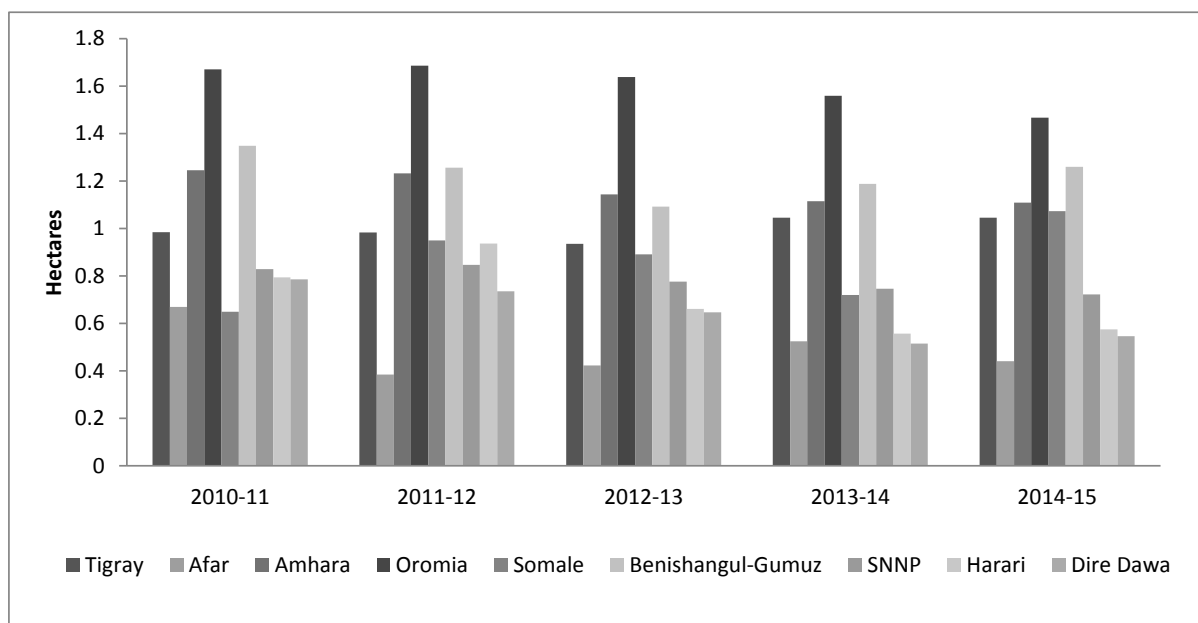

Figure 1: Average farm size in Ethiopia, per region, for 2010-2015

Cereals are the main crop within smallholders, occupying 80.3% of the grain crops area and 87% of the production, followed by pulses with 13.3% of the grain crops area and 10% of production in 2014-15.

The use of inorganic fertilizers has increased in Ethiopia in the last 5 years, reaching 46%[1] of the total cultivated land in Ethiopia in the season 2014-15 (see Figures 2 and 3). Despite the general increase of fertilisers use, we can find some regional differences. Thus, the region of Amhara registered the highest use of both Urea and DAP whereas the regions of Dawa, Somale and Afar registered the lowest use.

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[1] The fertilized area reached 8.175.441 hectares of a total cultivated area of 14.327.306 hectares.
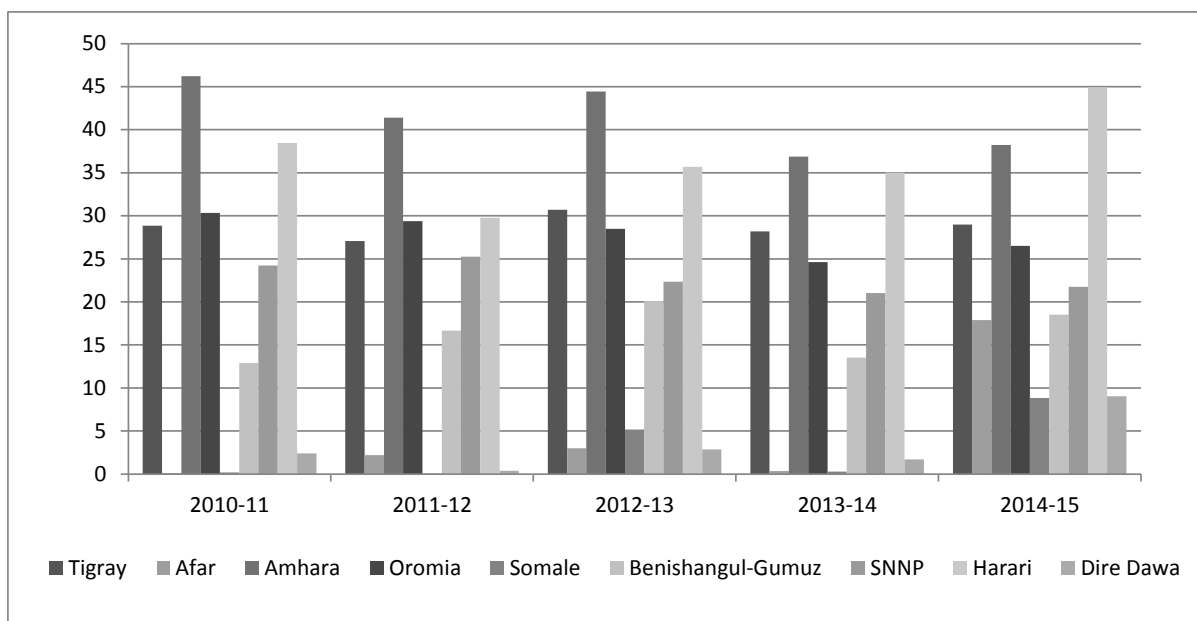
Figure 2: Average Urea used in Ethiopia, per region, for 2010-2015
(kg of Urea per ha of arable and permanent cropland)

In addition, it is worth mentioning that despite the percentage of households using fertilizer has increased also over time, results also show that fertilizer application is still low. About 58% of the Ethiopian farm households used chemical fertilizers, but a large proportion only uses small quantities. On average, farm households in Ethiopia used 28.2 kg of Urea per ha and/or 36.7 kg of DAP.
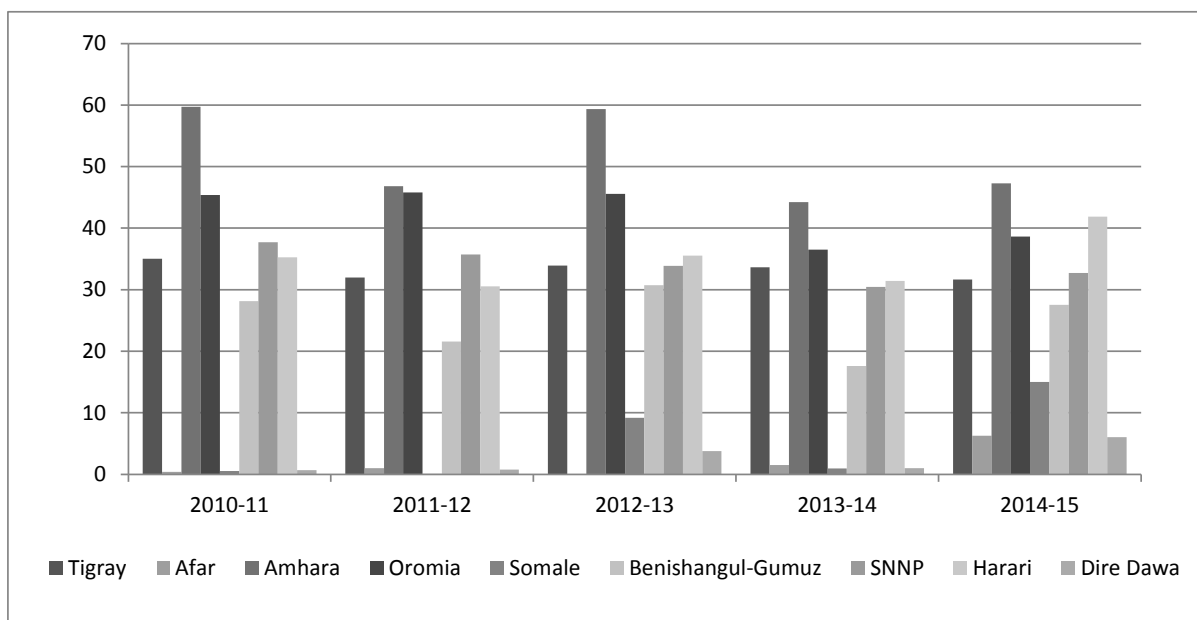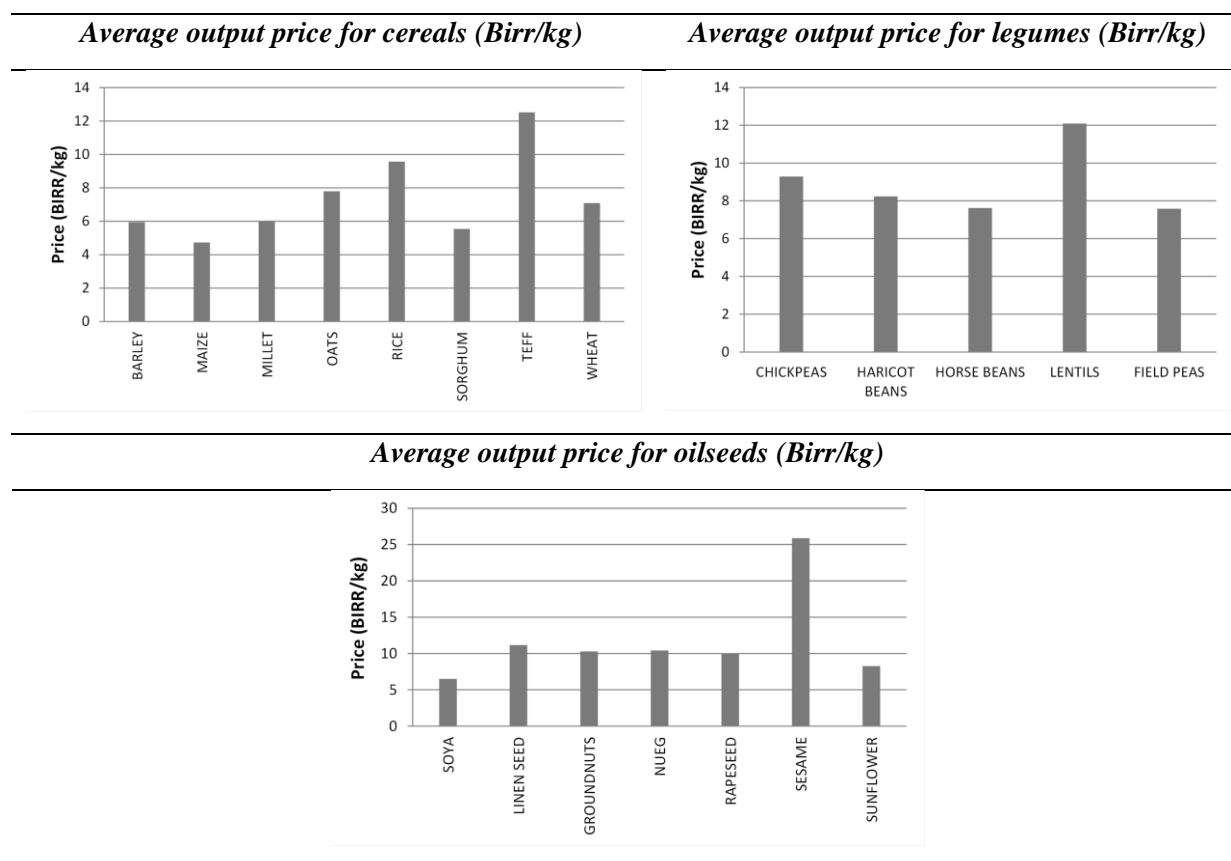

Figure 3: Average DAP used in Ethiopia, per region, for 2010-2015
(kg of DAP per ha of arable and permanent cropland)

More than 89% of the total chemical fertilizers in Ethiopia are used for cereals in 2014-15, being wheat (49.91 kg of DAP and/or 32.44 kg of Urea), maize (40.78 kg of DAP and/or 33.13 kg of Urea) and teff (41.35 kg of DAP and/or 30.70 kg of Urea) the crops that use the highest volume of fertilizers on average.
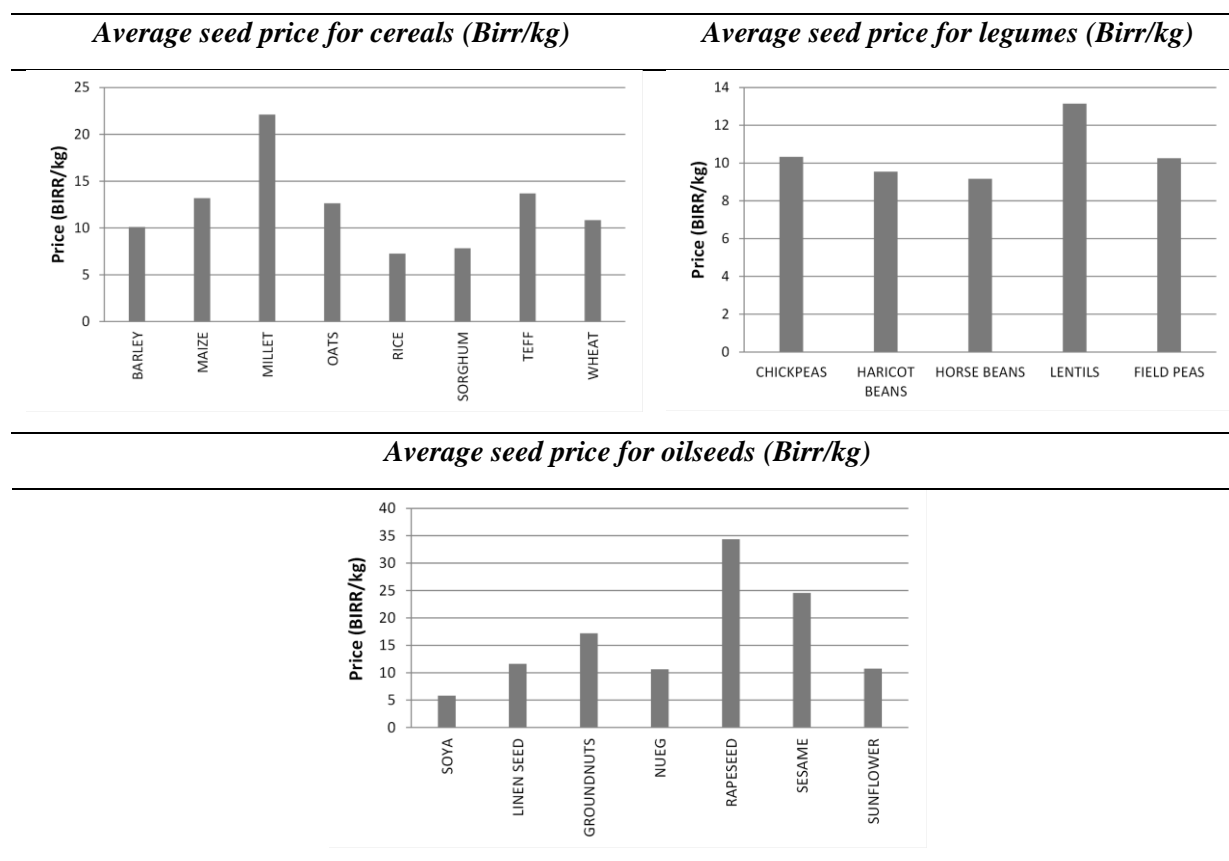
2.2. Input prices

As it is described above, the AgSS survey is focused on crop production and inputs use, but no price information is included. In order to cover this limitation, output and input (i.e., DAP, urea and seed) prices were obtained from the dataset of farm households included in the 2013-14 Living Standard Measurement Survey – Integrated Survey of Agriculture (LSMS-ISA), developed by the World Bank. This sample includes 5,262 households involved in agriculture and living in rural areas and small town across Ethiopia, being representative at the national level.

Average output price for cereals (Birr/kg)	*Average output price for legumes (Birr/kg)*

Average output price for oilseeds (Birr/kg)

Figure 4: Average price for crops in Ethiopia, 2013-2015

Output and seed prices were obtained by zone and crop levels. Figures 4 and 5 show information on national averages for some crops of relevance in the country. Among all the crops included, we can see that sesame reaches the highest average price per kg at country level (25.87 Birr/kg), followed by teff (12.52 Birr/kg) and lentils (12.09 Birr/kg).

Average seed price for cereals (Birr/kg)

Average seed price for legumes (Birr/kg)

Average seed price for oilseeds (Birr/kg)

Figure 5: Average price for seeds in Ethiopia, 2013-2015

Fertilizer prices were obtained at zone level (see Figure 6 on regional average prices per type of fertilizer). We can see that there are not significant differences on fertilizer prices at regional level due to the policy of subsidised price offered by the Ethiopian government.
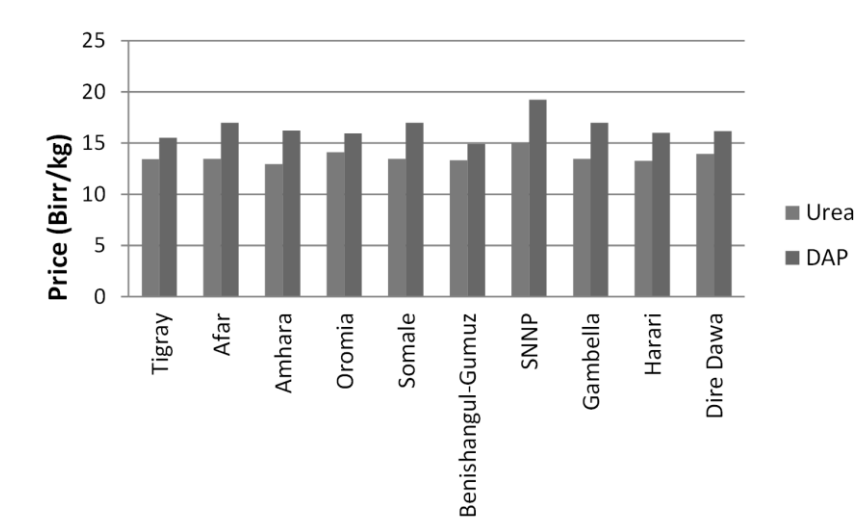
Figure 6: Average price for fertilizers by region in Ethiopia, 2013-2015

2.3. Methods: FSSIM-Dev model

To conduct an ex-ante analysis of the two fertilizer subsidy programs (universal and targeted) defined for Ethiopia, the Farm System Simulator for Developing Countries (FSSIM-Dev) model is used ((Louhichi and Gomez y Paloma, 2014). FSSIM-Dev is a comparative static and non-linear optimization model which relies on both the general household's utility framework and the farm's production technical constraints, in a non-separable regime. Such framework is suitable for analysing the decisions of farmers who are not fully commercialized or who operate with missing or imperfect markets.

FSSIM-Dev takes into consideration five key features of developing countries' agriculture, such as non-separability of production and consumption decisions, interaction among farm households for market factors, heterogeneity of farm households with respect to consumption baskets and resource endowments, inter-linkage between transaction costs and market participation decisions, and the seasonality of farming activities and resource use.

The principal outputs generated by FSSIM-Dev for a specific policy scenario are forecasts on resource use, agricultural production, food consumption, market factors exchange, farm household income and poverty level at farm household and aggregated levels (Louhichi et al., 2013; Louhichi and Gomez y Paloma, 2014).

FSSIM-Dev maximises farm household income subject to resource constraints (includes land and labour), cash, market clearing conditions, linear expenditure system (LES), price bands and complementary slackness conditions.

$$\text{Max } U = \sum_h w_h R_h$$

s.t.:

Resource constraints
Linear expenditure system (LES)
Price bands & complementary slackness conditions
Market clearing conditions
Cash constraint

where *U* is the value of the objective function, *h* denotes a farm household and *w* its weight within the village, region or country and *R* is the farm household expected income. For more details on the mathematical structure of the model and its functioning, see Louhichi and Gomez y Paloma (2013).

Farm household income (R) is defined as the income earned from all economic activities of a family living in the same household and is composed of three components: agricultural income, income from marketed factors of production (non-farm wages, rent of land and equipment) and off-agricultural/farm incomes. Agricultural (farm) income is defined as the value that farm-households have earned by selling or consuming their own agricultural products (i.e. self-consumption).The off-farm incomes are exogenously defined and can

originate from different sources such as non-farm salaries, petty trading, self-employed craftsmanship, pensions, transfer, donations, etc.
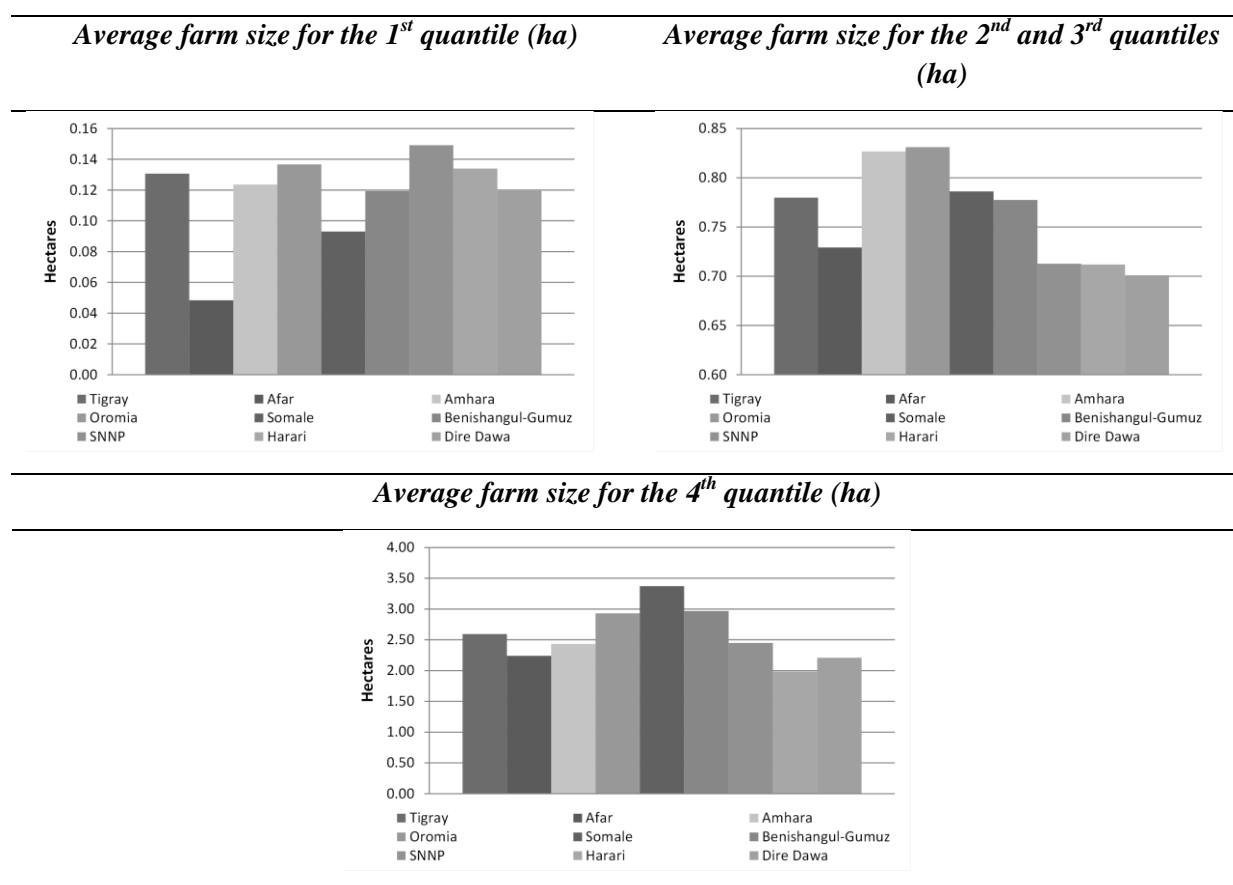
Agricultural (farm) income is computed as the sum of agricultural gross margin minus a non-linear (quadratic) activity-specific function. Gross margin is the total revenue from agricultural activities, including sales and self-consumption, minus the accounting variable costs of production activities. 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 replicate households' production and consumption decisions in a precise way, allowing to capture the effects of factors that are not explicitly included in the model such as price expectation, risk-adverse behaviour, labour requirement, capital constraints and other unobserved costs (Heckelei, 2002). The principal outputs generated by FSSIM-Dev for a specific policy scenario are forecasts on resource use, agricultural production, food consumption, market factors exchange, farm household income and poverty level at farm household and aggregated levels (Louhichi et al., 2013; Louhichi and Gomez y Paloma, 2014).

In this paper, the consumption module of FSSIM-Dev is not considered due to the missing data on both income elasticities and household purchases (AgSS only includes information about self-consumption in the household). Therefore, only the supply module was used to analyse the dataset. The model calibration is performed at the individual farm household level using Highest Posterior Density (HPD) estimation with prior information on supply elasticities (Louhichi et al., 2015). As a result, model parameters are calibrated and the model is able to exactly replicate the observed land allocation of crops.

2.4. Scenarios for targeted subsidies

A set of variables were used in order to define the households that will be targeted to receive a fertilizer subsidy, such as farm size, farm location and type of crops. These variables will be defined on the basis of the information included in the AgSS survey in 2014-15.

As it is commented above, Ethiopian agriculture is characterised by small *size* farms. Figure 6 illustrates this situation, showing that 75% of the sampled farms have holdings lower than 0.85 hectares on average, whereas only 25% manage larger holdings (greater than 2 hectares on average).

Average farm size for the 1ˢᵗ quantile (ha)	*Average farm size for the 2ⁿᵈ and 3ʳᵈ quantiles (ha)*

Average farm size for the 1ˢᵗ quantile (ha)   *Average farm size for the 2ⁿᵈ and 3ʳᵈ quantiles (ha)*

Average farm size for the 4ᵗʰ quantile (ha)

Figure 6: Distribution of farm size at regional level, 2015

Considering this situation, we can distinguish two types of farms: smallholders (lower than 1 hectare) and commercial (greater than 2 hectares).

The *location* of farms is also important to define the potential beneficiaries of the targeted subsidy policy. We consider as targeted areas those defined as high potential agricultural areas according to the Agricultural Growth Program I (AGP-I) that started on October 2010, and that aimed to increase agricultural productivity and market access for key crop and livestock products. The AGP-II, starting in 2015, has basically the same goal than its predecessor but benefitting more areas than AGP-I (61 additional woredas). In this paper, instead of woreda level to select the location of the farms, we use higher administrative levels (zones). Thus, a number of zones were selected according to the information included in the following table.

Table 2: Region and zone selected for targeted subsidies

Region	Zones
Tigray	3
Afar	
Amhara	6
Oromia	11
Somali	
Benshangul Gumuz	
SNNP	11
Gambella	
Harari	1
Dire Dawa	1

Regarding *crops*, we decided that, as occur in many other SSA countries, staple crops will be eligible to receive targeted fertilizer subsidies (e.g. cereals, legumes and oilseeds).

Taking into consideration the three variables, we can define two different policy scenarios for targeted fertilizer policy.

Table 3: Definition of policy scenarios

	Farm size	Location	Crops
Scenario 1 "universal fertilizer subsidy program"	All	All	All
Scenario 1 "targeted fertilizer subsidy program"	Smallholders (less than 1 hectare)	High-potential agricultural areas	Staple crops

3. Results and discussion

The model is implemented and calibrated for the whole AgSS sample of farm households in 2014-15. However, the implementation and the analysis of different scenarios are not yet fully performed. Such results are foreseen before the end of May 2016.

The paper has the potential to contribute to scientific discussions at the meeting in several areas. First, the topic of the paper is policy relevant in the context of climate change, price volatility and increasing of conflicts. Thus, the simulation results of the paper may contribute to rich and policy relevant conclusions by predicting based on farm characteristics (farm size, specialisation, socioeconomic and household characteristics, etc.) which type of farming may adopt the proposed fertilizer programs (flexible and targeted) and examining how these programs may affect productivity and farm household livelihoods. Secondly, this is one of the few papers simulating the distributional effects of fertilizer programs across the farm household population. Finally, the paper is methodologically innovative and employs an

optimisation model which attempts to simultaneously reproduce farm household production and consumption decisions in a non-separability regime.

Disclaimer

The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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