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GM Maize in Ethiopia

An Ex Ante Economic Assessment of TELA, a Drought Tolerant and Insect Resistant Maize

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Abstract

GM Maize in Ethiopia: An ex ante economic assessment of TELA, a drought tolerant and insect resistance maize.

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Ethiopian economy has grown at an average rate that surpasses that of almost any other economy in the region over the last two decades. At the center of this development is the high priority placed on accelerating agricultural growth and achieving food security and poverty alleviation. Over the years, maize has become a main food security crop, widely produced and consumed by smallholder farmers, second only to teff in terms of area. Despite the sustained growth of maize production over the years, its yields continue to be lower than the world's average. Of the many abiotic and biotic constraints that maize faces, insect attacks and droughts are two critical ones. The genetically modified TELA maize can help address these constraints. This paper estimates the economic benefits of adopting this new technology and the opportunity cost that Ethiopia will incur if its adoption is delayed. The analysis is conducted using an economic surplus partial equilibrium model run with the newly developed DREAMpy software, data drawn from the Ethiopia Socioeconomic Survey, Wave 3 2015-2016, econometric estimations using these survey data, and other local data and sources. The estimations show that if the drought tolerant and insect resistant TELA maize is planted in 2023 the net present-value of benefits for producers and consumers would be around $850 million. Producers from the mid-altitude maize zone will be the main beneficiaries, given the targeted area of TELA maize. Consumers from all areas will benefit from the projected reduction in price. If the adoption of this new technology is delayed by 5 years, the estimated net present value of benefits will fall by 30 percent. These costs underscore the importance of having a regulatory system that is efficient, predictable, and transparent and ensures that the projected economic benefits are realized.

Keywords: Drought tolerant maize, insect resistant maize, TELA maize, DREAMpy, Economic surplus model, Ethiopia, GMO crops,

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1. INTRODUCTION

The strong performance of the agriculture sector in Ethiopia, growing at an average annual rate of 5.8 percent for more than 20 years (World Bank 2020a), occurred in the context of strong overall economic growth as a result of policies and incentives put in place since the mid-1990s (National Planning Commission 2017). Annual real GDP growth averaged 8.3 percent between 1995 and 2018 and 9.8 percent after 2004 (World Bank 2020a). This acceleration in Ethiopia's growth has been a key factor in the reduction of poverty. According to the World Bank (2020b), the poverty headcount as a percentage of population at $1.90 a day (2011 PPP) declined from 71 percent in 1995 to 31 percent in 2015. Most of this decline in poverty is attributed to a fall in headcount poverty in rural areas.

Agriculture has been at the center of these developments since 1991 when the country formulated its Agricultural Development-Led Industrialization (ADLI) strategy that placed very high priority on accelerating agricultural growth and achieving food security and poverty alleviation (Rashid and Dorosh 2012). Since then, economic transformation has been a strong policy priority of the Government of Ethiopia (GoE). Over the last two decades, under the framework of ADLI, three development programs, namely the Sustainable Development and Poverty Reduction Program (SDPRP), the Plan for Accelerated and Sustainable Development to End Poverty (PASDEP), and the first Growth and Transformation Plan (GTP I) have been implemented between 2001/02 and 2014/15 amid spurring agricultural growth that brought about economic transformation.

More recently, a change in the national agenda and aspirations for agricultural and rural development towards commercialization, economic growth and poverty alleviation resulted in the national Agricultural Growth Plan (AGP). The AGP envisions the transformation of smallholder production systems from subsistence to commercial with increasing emphasis on diversification into high value products and intensification to improve crop productivity (FDRE-MoARD 2010). Moreover, the judicious use of yield enhancing inputs such as inorganic fertilizers and pesticides is among the policy instruments advanced by the GoE to achieve sustainable improvements in productivity of strategic agricultural commodities (EATA 2014, FDRE-MoARD 2010).

Despite changes in the focus and goals of the development strategy since its inception, the major staple crops -wheat, maize, and teff - widely grown by resource-poor smallholder farmers, have been a major component of the strategy with other crops being incorporated in later years. The aim for the major staple crops was to develop and release improved varieties accompanied by complementary technologies, providing credit and extension services to foster diffusion and adoption of the new technologies. In this regard, Abate et al. (2015), point to maize as a success story as it has become a strategic food security crop, widely produced and consumed by smallholder farmers, only surpassed by teff in terms of area. More than 35 improved maize varieties (IMV) have been released in the country since 1995 (Jaleta et al. 2013) as the result of a collaborative concerted effort involving international and national R&D set out to improve maize productivity throughout the diverse agroecologies of the country. Adoption increased from an estimated 8 percent of the area in 1997 to 28 percent in 2009 of which 26 percent is attributed to hybrids and only 2 percent to improved OPVs (de Groote et al. 2015). As a result, maize acreage in Ethiopia has doubled in two decades from 1.1 million hectares in 1995/1996 to 2.1 million hectares in 2015/2016 (Meher season), while productivity has increased from 1.52 t/Ha in 1995/1996 (CSA 1996) to 3.4 t/ha in 2015/2016 (CSA 2016). The national maize production has grown about fourfold to 7.1 million tons in 2015/2016 (CSA 2016) compared to 1.7 million tons in 1995/1996 (CSA 1996). More than eight million farmers were producing maize in Ethiopia in 2015/2016 and according to Abate et al. (2015) more than 95 percent of the total maize area and production in the country is covered by smallholder farmers.

For smallholder farmers in maize-based systems, maize is directly associated with their food security. Data on crop and livestock product utilization collected in 2017/2018 as part of the Agricultural Sample Survey (CSA 2017), show that up to 76 percent of maize grain produced was consumed at home on average, with sales representing only 12 percent of production. In the maize-based systems, no other cereal crop produced reaches this level in terms of retention for home consumption.

Despite the impressive development of maize production in the last two decades, average yield in Ethiopia for the period 2015-2018 (3.6 tons/ha) was still lower than the world's average for the same period (5.8 tons/ha) according to FAO (2020). A significant portion of this yield gap is attributable to biotic and abiotic stresses (Worku et al. 2012, Abate et al. 2017). Keno et al. (2018) point out that some of the main abiotic factors affecting maize production and productivity are drought, heat, soil acidity, frost and poor soil fertility mainly in N and P. Biotic stresses hindering maize production in Ethiopia include several diseases (e.g., Grey Leaf Spot, Common Leaf Rust, Maize Streak Virus), parasitic weeds (mainly *Striga hermonthica*), and insect pests such as the maize stemborer , maize weevils and the newly emerged fall armyworm (Keno et al. 2018).

Adding to present biotic and abiotic stresses, the future effects of climate change in Ethiopia will enhance the impact of these stresses on maize production. The spread of insect pests, plant diseases and invasive alien plant species to new regions, as the world's climate changes, is a threat to farmers in Ethiopia, a climate change vulnerable country due to its agriculture led economy (see for example, Abera et al. 2018, Conway and Schipper 2011). The high variability of the terrain and climate in Ethiopia will result in extremely different responses of current agricultural systems to climate change which will require further efforts in R&D investment.

To tackle these challenges, the Ethiopian government has added biotechnological approaches to plant breeding that can help reduce time and costs and potentially increase efficiency in development of new technologies. One of such technologies is genetically modified (GM) crops like insect resistant or *Bacillus thuringiensis* (Bt) and drought tolerant crops (Juhar and Semere 2017). Until recently, lack of locally generated evidence on the technical feasibility, economic profitability and environmental safety coupled with misinformed public opinion hampered the development and deployment of GM crops.

Ethiopia had until recently a biosafety law based on strict precautionary principles. This 2009 biosafety Law was amended in May 2015, when the Ethiopian parliament enacted 'A Proclamation to Amend the Biosafety Proclamation' that paved the way for the use of GM technologies. In 2016, the Ministry of Agriculture's requested the approval for importation of genetically modified (GM) insect resistant cotton seeds for field trials and research from the Ministry of Environment, Forest & Climate (MEFC). Following field trials, in 2018 Ethiopia approved the commercial cultivation of GM cotton. The Ministry also issued a five-year permit to conduct confined trials on drought-tolerant and insect-resistant maize, known as the TELA maize project. This project was developed under the philanthropic Water Efficient Maize for Africa (WEMA), a public-private partnership under the management of the African Agricultural Technology Foundation (AATF). The TELA maize field trials in Ethiopia are the first ones of a GM food crop.

Although TELA maize had shown significant scientific progress, local estimations of the potential benefits of TELA maize were lacking. This study focuses on generating this local evidence on the benefits of this specific technology that could then facilitate informed decisions by policy makers.

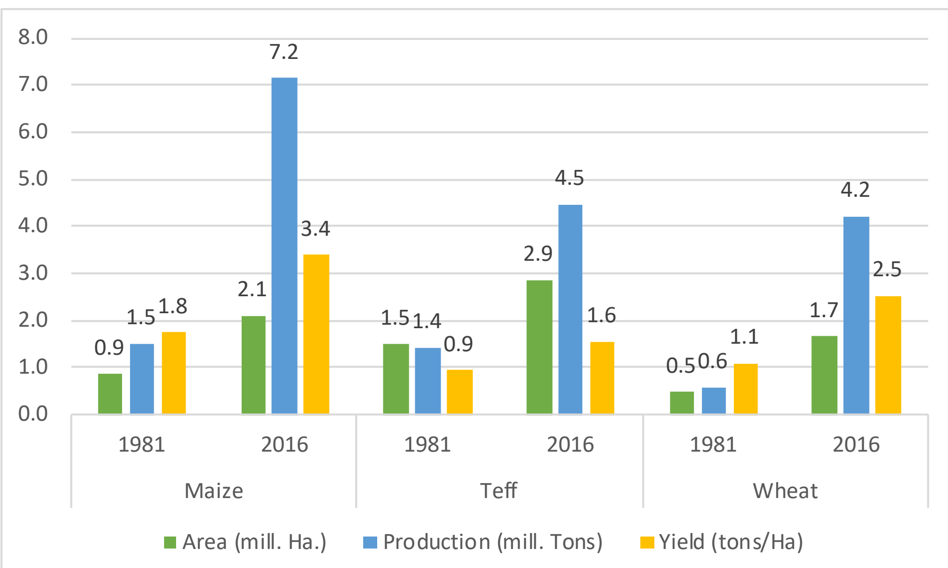
The discussion paper is organized into seven sections. Following this introduction, section 2 presents a characterization of maize production in Ethiopia. Section 3 discusses the choice of maize and traits considered in the evaluation. Section 4 describes the model and analytical approach. The next section describes the data sources used, as well as the assumptions and estimations of specific parameters. Section 6 then presents and discusses results. The last section concludes with implications of the study for GM research and policy.

2. MAIZE ECONOMIC RELEVANCE AND PRODUCTION CHARACTERISTICS

Background maize production data

Maize stands out as a success story of the ambitious agricultural productivity development goals of the Ethiopian government to lift millions of smallholder households out of food insecurity (Abate et al. 2015). Through a collaborative research effort between national and international research institutes, new improved varieties adapted to and grown in diverse agroecologies have been released and commercialized. Because of these efforts, maize has become the major cereal staple crop in terms of production and productivity, only surpassed by teff in terms of area (Jaleta et al. 2018). About 95 percent of the total maize in the country is cultivated by smallholder farmers (Abate et al. 2015) and the crop is planted in all the major agroecological zones up to altitudes of 2400 m.a.s.l. (EARO 2000). As shown in Figure 1, over the last 35 years (1981 to 2016), maize production increased 4.7 times, driven by the expansion of area, which doubled. This growth in area was coupled with a significant increase in yields, from 1.8 tons/Ha to 3.4 tons/Ha during this period.

Figure 1– Area, production and productivity of major cereal crops in Ethiopia, 1981 and 2016

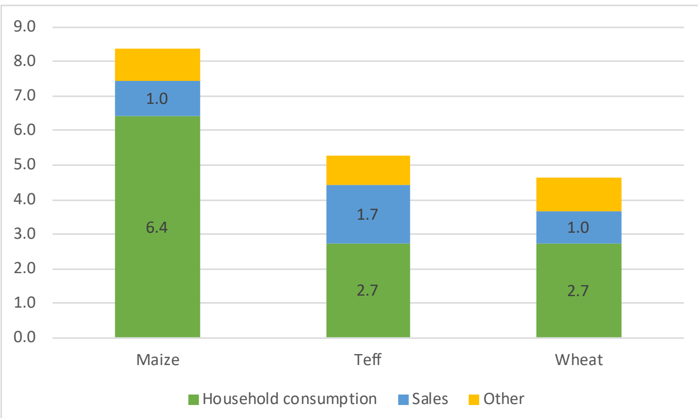


Source: CSA, various years.

Data for the 2017/18 major production season (*meher*) indicate that maize production reached 8.4 million ton planted in 2.1 million hectares, involving 10.5 million farmers (CSA 2018). This gives an average productivity of 4.0 tons/Ha. As a result of these developments, maize has become a strategic food security crop for smallholders. As shown in Figure 2, most of the production of maize (76 percent) is self-consumed, compared to 51 percent of self-consumption of teff and almost 60 percent of wheat.

Farmer's perception on own-food security status is directly related to the amount of maize harvested, which is again related to maize productivity. The latter is affected by varietal performance, drought and pest incidence. Hence, interventions directed towards improving the production and productivity of maize would have far reaching consequences not only on food security and overall welfare of smallholder farmers and low-income urban consumer, who depend on maize for the daily diet, but also on the capacity to generate surpluses to increase exports.

Figure 2– Production and utilization of major cereals, 2018 (million tons)



Source: CSA (2018)

Note: "Other" uses are seed, wages in kind, and feed.

Technology, inputs, and adoption of improved varieties

The Ethiopian National Agricultural Research System (the Ethiopia Institute of Agricultural Research, EIAR, and Regional Research Institutes, RARIs) in partnership with international research institutes have been vigorously engaged in the generation of improved maize technologies suitable for the various maize growing environments of the country. Over 60 improved maize varieties (hybrids and open pollinated varieties) with associated agronomic and crop protection practices have been released or registered in the country since the 1970s (MoA 2012). Over the last 20 years the maize breeding program has also been working to incorporate drought tolerance and quality traits such as protein quality, pro-vitamin A (yellow) and stover/feed quality traits (Gemechu et al. 2016, Adefris et al. 2015, Zaidi 2019).

Nationwide technology demonstration programs conducted throughout the country involving smallholder maize farmers, researchers, extension agents and other stakeholders attested benefits of using improved maize varieties. Yet, despite the release of a good number of improved maize varieties that are allegedly adapted to a wide range of maize growing environments, the use of certified improved seeds by farmers, though encouraging, is still below expectations.

For instance, maize technology adoption studies conducted in the major maize hubs of the country by Berhanu et al. (2007) found that 69 percent of farmers were using improved maize variety in 2001 compared to 63 percent in 1999. Similarly, a study by Getachew et al. (2010) conducted in the Rift Valley of Ethiopia reported about 53 percent of the better off households adopted improved drought tolerant maize (IDTM) varieties and planted them on 23 percent of their cultivated land. On the other hand, 47 percent of resource-poor households adopted these varieties to cultivate 20 percent of total area planted.

De Groote et al. (2014), defining rate of adoption as the proportion of households using freshly purchased (un-recycled) improved maize varieties, found that about 31 percent of the farmers planted improved maize varieties. The same study indicated that the hybrid maize BH-660 was grown by 27 percent of households on about 21 percent of the maize area, while BH-540 was grown by about 6 percent of the farmers on about 9 percent of the maize area during the same season. A later study by Chilot et al. (2016), aimed at tracking maize varietal adoption using DNA fingerprinting techniques, indicated that 61.4 percent of respondents used improved maize varieties. This study also revealed that only 30 percent of the farmers claim to know the specific name of the variety they cultivated. Farmer knowledge of cultivars, however, are restricted to only four maize hybrids, namely, BH-660, BH-540, BH-140 and Shone (Chilot et al. 2016, de Groote et al. 2014, Berhanu et al. 2007).

It has been well documented (see Verkaart et al. 2018) that smallholder farmers in Ethiopia and all over Africa face multiple constraints , including farm size, labor availability , human capital, access to credit, land tenure, all of which help explain the limited adoption of improved varieties. Nevertheless, there are technologies and crops that farmers with similar limitations have successfully adopted. Verkaart (2016) demonstrates that adoption, despite these existent limitations, can still be widespread for technologies and crops whose benefits clearly and substantially outperform the locally used ones, as it was the case for improved chickpeas in Ethiopia .In similar fashion GM crops in developing economies have been widely adopted India, Pakistan, China, and Brazil, among others

Maize producer's data

The estimations presented in this study are mainly based on detailed information of maize-producer households in Ethiopia , obtained from the Ethiopia Socioeconomic Survey , Wave 3 (**ESS3**) 2015-2016 (CSA 2017) implemented by the Central Statistical Agency of Ethiopia in collaboration with the World Bank Living Standards Measurement Study (LSMS) team as part of the Integrated Surveys on Agriculture program. We described below in detail the overall characteristics of maize producers in Ethiopia, data used later in the model estimations.

The ESS is a nationally representative survey covering more than 5,000 households in rural and urban areas. and was implemented in 433 enumeration areas (EAs) out of which 290 were rural, 43 were small town EAs, and 100 were EAs from major urban areas. The data on rural households included in the ESS are collected as a panel survey and are a sub-sample of the annual Agricultural Sample Survey (AgSS). The first and the second waves were implemented in 2011/2012 and in 2013/2014 respectively. The data used in this study corresponds to the third wave implemented in 2015–2016, refer to hereafter as ESS3. The survey provides plot-level data on area (measured using GPS), production, input use including pesticide, labor use (family and hired labor), agricultural assets and total costs.

We use data from ESS3 to estimate adoption of improved varieties, as well as other parameter that feed into the estimation of producers and consumers benefits . First, we grouped households in quintiles of total farm area which we numbered Q1 to Q5, with Q1 being the group of households with the smallest farm area and Q5 the group with the largest area. Table 1 shows the average household size, farm and maize area and assets like livestock and number of ploughs and carts by quintile group. Average farm area of maize producers is 1.8 hectares and goes from 0.2 hectares on average for households in Q1 to 4.1 hectares in Q5. The average area of maize is 0.31 hectares or 23 percent of total farm area on average for the five groups. Households in Q1 cultivate 0.06 hectares of maize, a very small area in absolute terms but it represents 34 percent of total farm area of an average farmer in this group. Producers in Q5 cultivate more than half hectare of maize which represents 14 percent of farm area. The share of maize area in total farm area in Q2, Q3 and Q4 is 28, 25 and 18 percent, respectively.

Table 1– Maize producer households: size and assets by quintile group

	Q1	Q2	Q3	Q4	Q5	Average
Household size	4.3	4.9	5.4	5.9	6.3	5.5
Farm area (Ha)	0.2	0.6	1.1	1.9	4.1	1.8
Maize area (Ha)	0.06	0.18	0.28	0.34	0.56	0.31
Share of maize area (%)	34	28	25	18	14	23
Maize production (kgs)	179	534	717	900	1,631	868
Maize production/household size (kgs)	41	108	134	152	261	150
Number of oxen	0.3	0.6	1.0	1.3	2.3	1.2
Number of cattle	1.6	1.8	2.3	3.0	5.4	3.0
Number of sheep & goats	2.0	2.1	2.1	2.8	3.8	2.6
Number of donkeys, mules & horses	0.2	0.5	0.7	0.8	1.1	0.7
Number of ploughs	0.5	0.9	1.1	1.2	1.5	1.1
Number of carts per 1000 households	59	25	69	35	79	55
Number of motorized transports per 1000 households	31	2	11	7	10	11

Source: Authors based on data from EES3 (CSA 2017)

One characteristic of Q1 group that stands out in Table 1 is the counterintuitive fact that despite having the lowest production of maize this group has the highest number of motorized vehicles among all quintiles, as well as one of the highest number of carts. The data shows that Q1 households are not dependent on farming for their livelihoods and are more likely to live near urban areas, which is a plausible explanation for the higher number of vehicles (motorized and carts).

Table 1 also shows average livestock assets of the different groups. Households in Q1 and Q2 appear to be constrained by the scale of their operation as reflected in the average number of oxen. Less than one of every three households own an ox. This value doubles for households in Q2 where two of every three households own an ox. According to Table 1, given the technology and the level of capitalization of Ethiopian households, farms need at least one hectare to be able to justify ownership of an ox and a plough. This minimum scale is achieved by the average Q3 producer who owns 1.0 oxen and 1.1 ploughs. Ownership of cattle seems to be proportional to total farm area but even farmers in Q1 own more than one cattle. Ownership of donkeys, mules and horses is more dependent on farm area as an indicator of household wealth: only households in Q5 own on average more than one of these animals, while only 2 in 10 of households in Q1 have access to these assets. In contrast, ownership of sheep and goats is poorly correlated with farm size, which is probably indicating that small ruminants are mostly kept for consumption and their number depends more on household size than on farm area. Notice that production per capita in group Q1 is about half of the average maize consumption of 78 kgs per capita in Ethiopia (Berhane et al. 2011). Households in Q1 as well as those in Q2, producing 108 kgs of maize per capita, are likely producing for self-consumption, while households in Q3 to Q5 are surplus producers of maize with Q3 probably obtaining surplus production in good years. Q4 and Q5, with maize production per capita of 152 and 261 kgs seem to be surplus producers that can assign a significant share of production to the market or use as input of other activities.

Based on the results in Table 1, we classified maize producers into three main groups with contrasting characteristics, as shown In Table 2. The first group, which includes households in Q1 and Q2, are small scale producers with farm area of less than half hectare and 0.13 hectares of maize. These households produce 78 kgs of maize per capita, like the country's average consumption of maize. We take this as an indication that the average farmer in this type produces maize for self-consumption but about half of farmers in this group do not have the resources to produce enough maize to reach Ethiopia's average consumption per capita. We will refer to this group as the "small-scale" farmers. The second group includes households in Q3 and Q4. The average farm area of households in this type is 1.5 hectares and they produce 144 kgs of maize per capita which makes them self-sufficient farmers with the capacity to sell some surplus production in the market. The average type in this group allocates 21 percent of total farm area to maize and they own 1.1 oxen and 1.1 ploughs per household on average. This is the group of "self-sufficient" maize producers. Finally, large maize or surplus maize producers are those in Q5 as described above. They have the largest farm area (4.1 hectares), they produce 261 kgs of maize per household member (more than three times average consumption in Ethiopia) and they own, on average, 2.3 oxen.

Table 2– Household size and assets by household type

	Small-scale	Self-sufficient	Surplus	Average
Household size	4.6	5.7	6.3	5.5
Farm area (Ha)	0.4	1.5	4.1	1.8
Maize area (Ha)	0.13	0.31	0.56	0.31
Share of maize area (%)	29	21	14	23
Maize production (kgs)	362	812	1,631	868
Maize production/household size (kgs)	78	144	261	150
Number of oxen	0.4	1.1	2.3	1.2
Number of cattle	1.7	2.7	5.4	3.0
Number of sheep & goats	2.1	2.4	3.8	2.6
Number of donkeys, mules & horses	0.3	0.7	1.1	0.7
Number of ploughs	0.7	1.1	1.5	1.1
Number of carts per 1000 households	42	51	79	55
Number of motorized transports per 1000 households	16	9	10	11

Source: Authors based on data from ESS3 (CSA 2017)

Table 3 presents yields and input coefficients for maize production for the three household types as defined above. Surplus producers show the highest labor productivity as expected: 25 kgs per day of work compared to 13 and 9 in self-sufficient and small-scale producers, respectively. Surplus producers still show the highest yields among the three household types although differences between types don't seem to be significant (2,927 kgs compared to 2,884 and 2,615 kgs in small-scale and self-sufficient types, respectively) even though they use about the same amount of fertilizer per hectare than the other two types while cultivating an area five times larger than that of small-scale producers. Instead, surplus producers use more than twice as much pesticides and herbicides (61 birr/Ha) than small-scale producers (27 birr/Ha) and 50 percent more than self-sufficient households (38 birr/Ha).

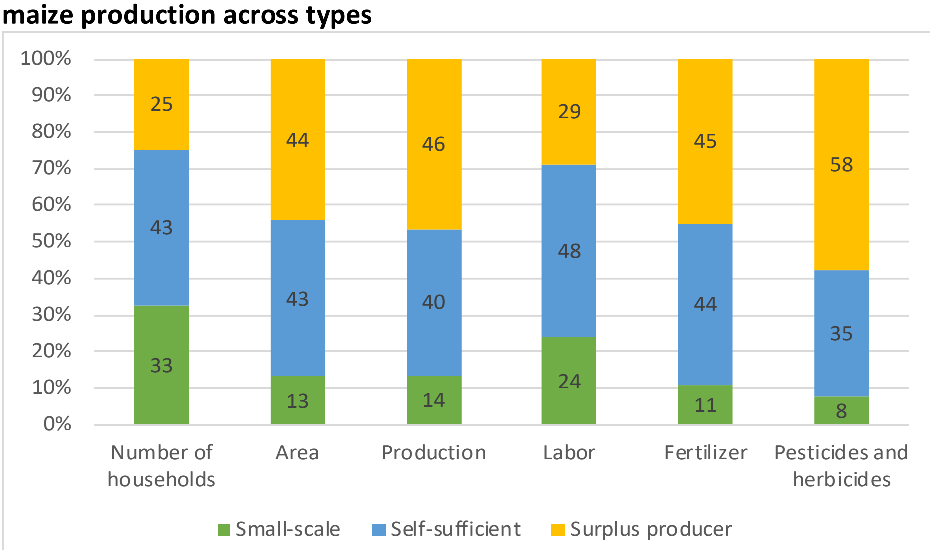
Table 3– Maize production coefficients by household type

	Small scale	Self-sufficient	Surplus producer
Output per day of labor (kgs)	9	13	25
Fertilizer per day of labor (birr)	3.5	6.9	11.7
Pesticide and herbicide used per 100 days of labor (birr)	8.3	18.4	51.4
Area worked by 100 days of labor	0.30	0.49	0.85
Yield (kgs/Ha)	2,884	2,615	2,927
Fertilizer per hectare (birr)	1,138	1,415	1,384
Pesticide and herbicide per hectare (birr)	27	38	61

Source: Authors based on data from CSA (2017)

The allocation of resources across household types is presented in Figure 3. Forty-three per cent of total maize producers are classified as self-sufficient producers, 25 percent are surplus, and one-third are small-scale producers. At 33 percent, small-scale maize producers are significant in number but they only account for 13 percent of maize area 14 percent of total output and of a small proportion of inputs used, except for labor (24 percent of total labor used in maize production). Surplus producers are 25 percent of all maize producers, but they cultivate 44 percent of maize area and produce 46 percent of total maize output. Self-sufficient households represent 43 percent of all household producing maize. Collectively, they cultivate almost the same area than surplus households and produce 40 percent of total output. The use of fertilizer in the three household types is proportional to their cultivated area but surplus farmers apply almost 60 percent of pesticides and herbicides used in maize, compared to 35 percent in the case of self-sufficient farmers and 8 percent in small-scale farmers.

Figure 3– Share of household types in total number of maize producers and allocation of resources for maize production across types



Source: Authors based on data from CSA (2017)

Maize production zones

The ESS3 also provides detailed information on the climate and geography of each household's location, including average annual precipitation and altitude. The core dataset for the study includes Information on 3,335 plots in 1,708 households where maize was planted. Using sample weights, these 1,708 observations represent a total of 8.61 million households producing 7.42 million tons of maize in 2,67 million hectares.[4]

Households were grouped in five different maize production zones defined using two variables relevant for the analysis at hand: altitude and precipitation. Given that the TELA maize variety to be introduced is adapted to mid-altitude areas (between 1,000 and 1,800/2,000 meters), we assume as high-altitude all areas located above 2,000 meters. We define mid-altitude areas as those located at altitudes between 1,000 and 2,000 meters, and lowlands as those areas below 1,000 meters. The mid- and low-altitude zones were further divided based on average annual rainfall into moisture stress (less than 800 mm/year) and sub-humid (at least 800 mm/year). This classification results in five agroecological zones for maize production, shown in Table 4.

Table 4– Maize production zones based on altitude and rainfall

	Defined maize production zones		**Altitude (meters)**	**Rainfall (mm/year)**
1	High-altitude sub-humid & moisture stress	(HA)	>2,000	all
2	Mid-altitude sub-humid	(MASH)	1,000-2,000	>=800
3	Mid-altitude moisture stress	(MAMS)	1,000-2,000	<800
4	Low-altitude sub-humid	(LASH)	<1,000	>=800
5	Low-altitude moisture stress	(LAMS)	<1,000	<800

Source: Authors classification based on ESS3

The ESS3 is representative at the country level but it is not representative of household maize producers in the different production areas. To work with nationally representative quantities of maize within each agroecology, we adjusted output to add up to total output in each zone within major regions in Ethiopia as reported by the CSA for the year 2015-2016 (CSA 2016a and 2016b). As our analysis focus on the impact of drought and attack of stemborer on yields, we adjusted the area in each zone to obtain the average yield reported by CSA. The adjustment of area and crop is done proportionally at the plot level, so we keep the heterogeneity of results from the ESS3 with output total adding up to zone's totals (and region and country totals) and yields matching average yields by zone. We then use the information on average precipitation and altitude at the household level to group

[4] These numbers result after cleaning the data for outliers, mostly plots with unlikely high yields in this sample and adjusting areas and output by region and zone to match totals provided by the CSA for the year 2016 as explained below.

households by agroecology, with total output now adding up to total output reported by CSA. Total maize area is not exactly the same as that reported by CSA because it was used as the adjustment variable to obtain CSA yields by zone.

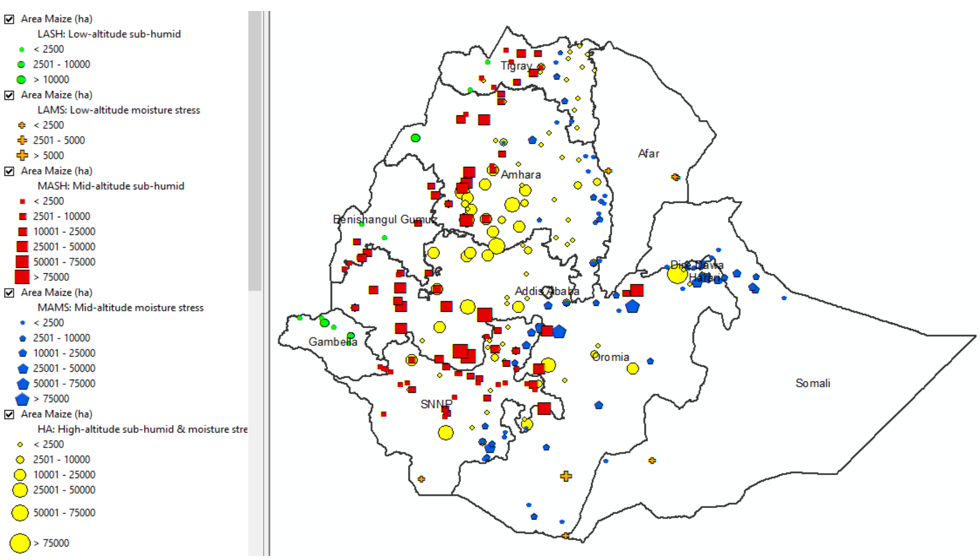
Table 5 shows the final values for maize area, production, and yields by production zone and Figure 4 presents the spatial distribution of maize area in 2015-2016 by maize production zones, obtained from adjusted figures of the ESS3.

Table 5– Maize yield, output and area, by production zone

Maize production zone		Area (Ha.)	%	Production (Tons)	%	Yields (Tons/Ha.)
High-altitude sub-humid & moisture stress	(HA)	758,817	28.4	2,450,888	33.0	3.42
Mid-altitude sub-humid	(MASH)	1,219,752	45.6	4,045,446	54.5	3.32
Mid-altitude moisture stress	(MAMS)	643,554	24.1	866,522	11.7	2.22
Low-altitude sub-humid	(LASH)	41,419	1.5	47,676	0.6	2.34
Low-altitude moisture stress	(LAMS)	10,520	0.4	9,730	0.1	1.69
Total		2,674,062	100	7,420,261	100	3.13

Source: Elaborated by authors based on ESS3-and CSA (2016)

Figure 4– Maize production zones in Ethiopia

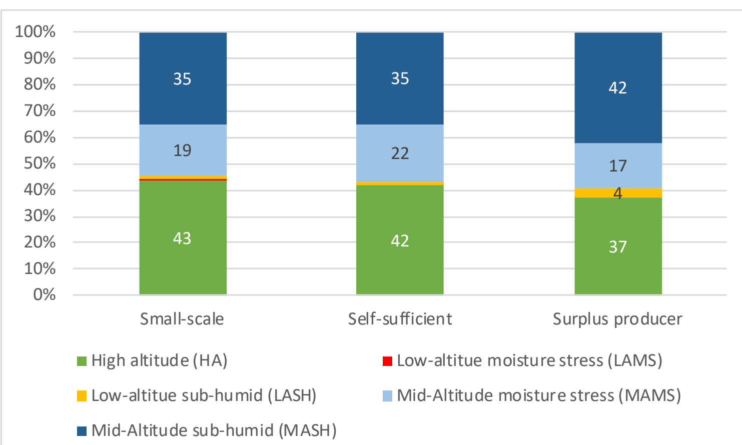


Source: Elaborated by authors based on ESS3 and CSA (2016)

The geo-reference for each household in ESS3 is used to depict the spatial distribution of maize area across maize production zones in Ethiopia (Figure 4). The figure shows the highlands (yellow circles) as the breadbasket of Ethiopia and a major maize production zone. From the highland backbone, altitude decreases rapidly towards Sudan in the west creating a mid-altitude corridor that goes roughly between the highlands and the western border of the country from Tigray in the north to southwest Oromia in the south (red squares). It is precisely in southwest Oromia that a significant share of the mid-altitude maize area is concentrated. The other major mid-altitude maize area follows the Rift Valley from Harar and Dire Dawa to the eastern border of the SNNP region. This is the area where most of the mid-altitude maize production is located (blue pentagon), alternating with mid-altitude moister stress maize in the south end of the Rift Valley. To the south and north of the eastern part of the Rift Valley, altitude decreases rapidly into the Somali and the Afar regions respectively. These are arid pastoralist regions with very little agriculture. The southwest end of the Rift Valley separates the central highlands from the Bale mountains in Oromia. Mid-altitude arid areas with poor conditions for production contribute with 15 percent of total output. The contribution of lowlands to total output is low (less than 2 percent).

We now combine the household classification with the definition of maize production zones to determine the spatial distribution of household types. Figure 5 shows the percentage of households of each type located in different production zones. About 40 percent of all household types are in high altitude (HA) areas while 35 percent of all small-scale and self-sufficient households and 42 percent of surplus producers are in the Mid-altitude Sub-humid (MASH) zone. About 20 percent of each household type are in the Mid-altitude moisture stress (MAMS) zone while only surplus types are relatively important in the Low-altitude Sub-humid (LASH) zone.

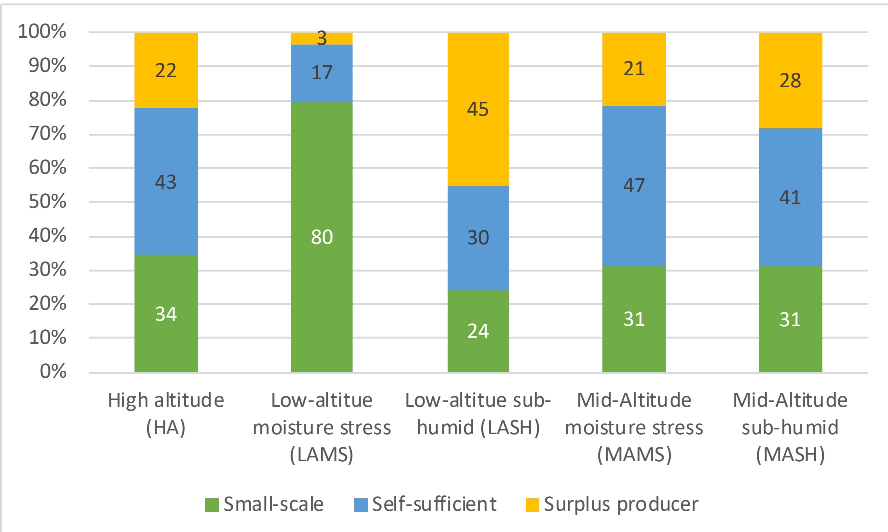
Figure 5– Distribution of maize producers across maize production zones, percentage



Source: Elaborated by authors based on CSA (2017)

Figure 6 presents the same information shown in Figure 5 but now looking at the contribution of each household type to the average household in each maize production zone. Mid-altitude zones show a very similar composition of household types, both with 31 percent of households of the small-scale type with MASH showing more surplus households (28 percent) than MAMS (21 percent). The opposite is true for self-sufficient households: they appear in greater proportion in MAMS (47 percent) than in MASH (41). The low-altitude zones include only a small share of households producing maize. The moisture stress LAMS zone is mostly composed by small-scale households (80 percent) while the LASH zone has a higher proportion of surplus producers than all other zones (45 percent), being one of the areas with higher potential for future expansion of maize production.

Figure 6– Importance of different household types in maize production zones, percentage



Source: Elaborated by authors based on CSA (2017)

In sum, maize stands out as a success story of the agricultural productivity development goals of the Ethiopian government to lift millions of smallholder households out of food insecurity. As part of this effort, agricultural research organizations in Ethiopia have been engaged in the generation of improved maize technologies that incorporate drought tolerance and quality traits and are suitable for the various maize growing environments of the country. These efforts have transformed maize in a strategic food security crop for smallholders. Of the 8.61 million households producing maize in 2015/2016, 76 percent were small farmers producing at or below the level of self-sufficiency. However, and despite progress made, food security of these farmers is still under significant risks, given that the use of improved seeds by farmers, though encouraging, is still below expectations, as none of these improved varieties has been able to reduce the combined threats that drought and pests represent for maize production. To further improved on the food security of rural and urban households, the Ethiopian government has added biotechnological approaches to plant breeding that can help reduce time and costs and potentially increase efficiency in development of new technologies. The next two sections look at Ethiopia's efforts to release the TELA maize variety and the estimated effects of its adoption on household's food security.

3. CROP–TECHNOLOGY SELECTION AND STATUS OF TECHNOLOGY

The challenge to feed a growing population and achieve food and nutrition security remains a priority in Ethiopia. Ensuring food security has been the priority agenda of the GoE that has identified several crops are as strategic food crops to address food insecurity. One of the strategies in place to reach this goal is developing and deploying improved crop varieties that reduce down-side risks of both biotic and abiotic stresses.

Crop and trait selection process

The GoE research and development priority efforts are focused on major staple crops widely grown by resource-poor smallholder farmers (EAIR 2017). Initially, maize and potato were selected as priority crops for ex ante economic analysis of the impact of the introduction of improved GM varieties. The final crop selection took into consideration the development stage of the GM technologies in other countries. These considerations were met by TELA maize, a project managed by the African Agricultural Technology Foundation (AATF) and that at the time was well under development in five African countries (Kenya, Mozambique, South Africa, Tanzania and Uganda). Since the selection process was completed, Ethiopia was added to the TELA project (2018) and soon after (2019) confined trials to identify suitable maize GM varieties were underway in the country. The GM maize focus of the TELA maize is to develop a variety that is resistant to stemborers, a major insect pest, and is also tolerant to drought. The rationale, in the context of Ethiopia, is explained below.

TELA project: Drought Tolerant and Insect Resistant Maize

Drought incidence of various intensities is not uncommon in Ethiopia, affecting different agroecological zones and maize production areas. . TELA maize was developed with the objective of mitigating drought risks in areas of high production potential, which in Ethiopia are the mid-altitude areas that fall between 1,000 and 2,000 m.a.s.l and where over 65 percent of production of maize is planted. It is in these high production areas where the occurrence of drought during the growing season can have the most devastating effect over maize supply.

TELA maize also offers protection to stemborers, one of the major biotic constraints to maize production and productivity in Ethiopia, where more than 30 insects attacking maize are recorded (Emana et al. 2008). Of these insects, six stemborer species namely, *B. fusca, C. partellus, S. calamistis, S. nonagrioides botanephaga, S. cretica Lederer, P. dubius* and *R.niger* are found to be important

(Assefa1985, Emana 2002, Emana et al. 2008). In terms of economic importance, however, *B. fusca* is prevalent at higher altitudes, higher rainfall and cooler maize growing areas, while *C. partellus* prevails in lower altitude, low rainfall and warm maize growing areas of the country (Emana et al. 2008). Grain yield loss due to stemborers vary immensely depending on type of variety cultivated, physiological stage of the crop at infestation and density of the pest which could range from 10 to 100 percent (Emana et al. 2002, 2008). Nonetheless, albeit for climatic and geographical differences, yield loss on maize due to uncontrolled stemborers on the average range from 30 to 40 percent (Emana et al. 2002, 2008). Besides stemborers, fall armyworm has emerged recently as one of the major threats to maize production.

Various stemborer management options are reported in the literature including cultural control (intercropping maize with non-cereal crops, residue management, adjusting planting dates), host plant resistant, biological and chemical controls (Emana et al. 2002, 2008). And yet, stemborer control on maize relies heavily on costly pesticides, that can affect human health and the environment, particularly when improperly managed.

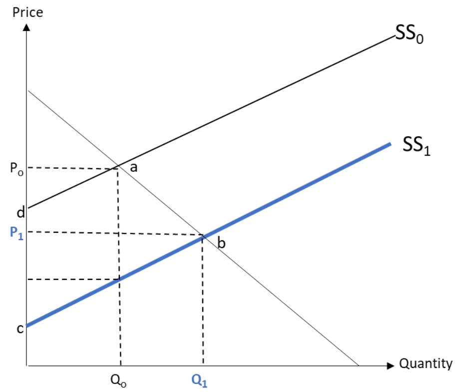
4. MODEL AND ANALYTICAL APPROACH

The ex-ante economic analysis of TELA maize presented in this study is conducted using a multiregion economic surplus model (ESM) as described by Alston et al. (1995). The ESM has been used extensively to evaluate research investments and investment allocation. The ESM has an advantage over other more sophisticated methods in that it is parsimonious in terms of data requirements and model handling, both key in the implementation of this project. According to Alston et al. (1995) the main drawbacks of their proposed ESM approach are that it ignores transaction costs, externalities, and general equilibrium effects, although the authors state that most of those factors can be at least partially addressed by incorporating them into the estimated cost and benefits variables. This study offers different scenarios to account for the variability in key parameters, such as adoption rates and expected yield changes. As we note in the next section, many of the parameters required to estimate the ESM are drawn from, and in some cases estimated using, the Ethiopian Socio-Economic Survey, Wave 3, 2015-2016.

Alston et al. (1995) describe in detail the ESM implemented in this report; the equations described below refer only to the basic model in a closed economy. The introduction of a technology—in this case, a GM technology—if effective, will enable producers to decrease their unit cost by reducing their input use and/or increasing their yield. This change is reflected in the shift of the supply curve from SS_o to SS_1, as depicted in Figure 7.

The technology-induced shift in the supply curve will result in a lower clearing price, moving the equilibrium price down from P_0 to P_1, with increments in quantities from Q_0 to Q_1. Producers gain because even though they are selling at a lower price, they can produce more due to the technology-induced cost change. Consumers gain because they benefit from the reduction in price. The net welfare effects of the technology-induced shift of the supply curve is measured as the net change in consumer surplus (ΔCS) and producer surplus (ΔPS), represented by the area *abcd* in Figure 7.

Figure 7– Measuring welfare effects of a technology through the induced shift of the supply curve



Source: Authors' linearized schematic interpretation.

Following the Alston et al. (1995, 210) notation, the net welfare effect in a closed-economy model can then be estimated according to equations 1 through 3, which use prices, quantities, elasticities, and the research-induced unit cost change due to yield increase or input cost reduction.

$\Delta CS = P_0 Q_0 Z\,(1 + 0.5Z\eta)$	Change in Consumer Surplus	(1)
$\boldsymbol{\Delta PS = P_0 Q_0 (K - Z)(1 + 0.5\,Z\,\eta)}$	**Change in Producer Surplus**	**(2)**
$\boldsymbol{\Delta TS = \Delta CS + \Delta PS}$	**Change in Total Surplus**	**(3)**

Where $Z = \left(K - \frac{K\,\varepsilon}{\varepsilon + \eta}\right)$ is the price reduction due to supply shift,

K = proportionate vertical shift of the supply curve induced by a cost reduction

ε, and η = elasticity of supply and demand, respectively.

This basic closed-economy ESM approach (equations 1 through 3) can be modified to estimate a multiregion technology adoption with associated regional production characteristics, used in this report and described by Alston et al. (1995, 212–218). The underlying assumption in this case study for TELA maize, is that although Ethiopian maize is internationally traded, we can treat Ethiopia as a small closed economy given the fact that maize international trade is small and has no influence over international prices. For this reason all estimated benefits will be accrued only in Ethiopia. Additionally, the fact that TELA target area is the mid-altitude zone, the assumption is that adoption will be limited in all other areas, but prices will fall across all regions, given the expected increase in production in the targeted TELA regions.

To conduct the ex ante assessment of TELA maize, this report uses DREAMpy (Dynamic Research Evaluation for Management, Python version), an IFPRI-developed open-source software that implements the ESM.

5. DATA SOURCES AND ESTIMATIONS

Regional data for maize production, yields, cost of production, and consumption to define the base year for the analysis were drawn from the third round of the Ethiopia Socioeconomic Survey 2015-2016 (ESS3) (CSA 2017, as referred in Section 2). According to the ESS3, agriculture is practiced approximately by 98 percent of the rural as well as 64 percent of the small-town households. The average household land area is 1.4 hectares and for the top five major cereal crops, the use of fertilizer ranges from approximately 38 (sorghum) to 83 (wheat) percent of crop area. About 31 percent of maize area uses improved seed while for other field crops the area under improved seed ranges from 2 to 8 percent.

On top of the plot-level data on area, production, input use, labor use, agricultural assets and total costs, ESS3 provides information on gender and detailed household characteristics, national consumption of maize (all households) and specific urban and rural consumption by region. As also mentioned in Section 2, ESS3 is not nationally representative for maize production, so data were adjusted so that output shares of all regions matched value shares of those same regions as reported by CSA. Regional maize movements were estimated using the data derived from this survey. National producer prices were drawn from ESS3 at the household level using quantity and value of maize production. Prices for each of the maize-production regions were then calculated as a weighted average of household level prices. We then use the average 2016 national maize producer price reported for Ethiopia by FAO (2020) as the reference price and adjust the regional prices from ESS3 to conform to the FAO price[5]. Data for R&D costs were supplied by local experts. Detailed information for all these data follows.

Yields and the Impact of Drought and Stem Borer Infestation

Probabilities

To determine the probability of drought in Ethiopia we used a “hot spot” map of risk reproduced by the Center for International Earth Science Information Network (CIESIN) from Bartel and Muller (2007, pp 5). Bartel and Muller (2007) calculated the probability of occurrence of drought in a given area of the Horn of Africa, including Ethiopia, within a given year calculated on 1° by 1° grid cells. In their analysis, Bartel and Muller assume that moderate to severe drought have occurred in a given month when the average

[5] For example, the average national price obtained from the ESS3 is used to express regional prices as a proportion of the national price. By multiplying these ratios by the average national price reported by FAO we obtain regional prices based on the FAO price that replicate price differences by region as obtained from the ESS3.

rainfall over a three-month period centered on that month is at least 1.5 standard deviations below the long-term monthly average rainfall. This approach compares the rainfall in a given month to the rainfall in that same month over the past 21 years. The calculation is performed independently for each grid cell, so the analysis should not be biased spatially or temporally. It is important to notice that defined in this way, drought relates to annual variability in precipitation relative to average precipitation in a period of 21 years and not to average precipitation only. In this context, dry areas do not necessarily show a higher probability of drought than humid areas.[6]

According to Bartel and Muller (2007), the most frequently affected regions by severe drought are eastern and western Ethiopia. Based on historical rainfall records, the chance that these regions will experience severe drought within the rainy season of any given year is greater than 40 percent (Bartel and Muller 2007). However, by overlapping drought risk with density of agricultural production per square kilometer, Bartel and Muller (2007) concluded based on exposure, that risks associated with drought are greatest in southwestern Ethiopia (roughly comprising the region of Gambela, the west of SNNP region, and part of southwest Oromia) and the Rift Valley. In some areas within this region, droughts in the rainy seasons are likely (more than 40 percent chance in any given year) and the exposure to drought is high (more than 30 percent agricultural land usage). Drought conditions are also likely in eastern Ethiopia, but relatively sparse agricultural land usage there translates into lower risk).

Several studies (Mwalusepo et al. 2015 , Goftishu et al. 2017, Keno et al. 2018, and Abate 2012, among others) have looked at the impact of stemborer on yields and the factors that predispose crops to infestation. We define the probability of infestation and damage following Wamatsembe et al. (2017) who, based on farmers evaluations, estimated the average frequency of significant stemborer damage at two years out of three, an average risk of 67 percent across all years. We applied this same risk value to all regions.

The main source of information used to determine yield losses was Wamatsembe et al. (2017). Although this study is for Uganda, it is particularly relevant to our analysis because it looks at yield changes due to drought and stemborer attack. As in the case of Ethiopia, stemborer damage and drought stress cause substantial losses in Uganda's maize production. According to Wamatsembe et al. (2017), average yield losses due to drought alone in SSA are estimated at about 33 percent as the result of dependence on rainfed conditions in regions with insufficient and or uneven spread rains during crop

[6] Notice that moisture stress or arid areas with low precipitation but little annual variation of rainfall (around a low average) are not considered drought prone areas under this definition but rather low-potential areas.

growth. Losses due to drought were about five percentage points higher for low input farmers than high input farmers (60 and 54 percent, respectively).

Stemborers are also a significant factor affecting maize yields in SSA. According to de Groote (2002), several studies for East Africa have shown losses to fall between 34 and 43 percent, depending on maize variety and planting time (high correlation between crop loss and late planting) among other factors. Wamatsembe et al. (2017) report yield losses to stemborer of 23.5 percent if stress occurs and 54.7 percent yield losses from drought. Wamatsembe et al. (2017) also found that yield losses due to stemborer infestation were higher for high input farmers (24 percent) than low input farmers (19 percent).

Based on these results we assume a higher yield loss to stemborer in the more productive zones of Ethiopia (MASH and LASH production zones). We assume that sub-humid zones will have smaller losses in percentage terms relative to moisture stressed zones due to drought. Finally, to analyze the impact of introducing a drought resistant and/or Bt maize variety, we assume that the TELA maize variety performs better than the conventional variety when insecticides are used (Wamatsembe et al. 2017). Probabilities of drought and insect attacks are shown in Table 6.

Table 6– Probability of different events in maize production

		Hazard probability of:				
		Losses from drought	**Losses from borer**	**Losses from drought & borer**	**No losses due to drought & borer**	**Total**
High-altitude	HA	0.08	0.52	0.15	0.25	1.00
Mid-altitude sub-humid	MASH	0.07	0.55	0.22	0.16	1.00
Mid-altitude moisture stress	MAMS	0.14	0.38	0.19	0.29	1.00
Low-altitude sub-humid	LASH	0.07	0.53	0.24	0.16	1.00
Low-altitude moisture stress	LAMS	0.15	0.37	0.20	0.28	1.00

Source: Elaborated by authors

Notes: Probability of "drought" results from multiplying the probability of drought by the probability of no infestation by stemborer. Similar procedure was followed for the probability of borer attack, losses from drought & borer and no losses. Probabilities of each event can be found in Table 7. The probability of some event not happening is 1-Probability of occurrence of that event.

Putting together the probabilities of losses due to drought and stemborer attack, and the estimated yield losses assumed for these events in the different maize production zones, we obtained the final assumptions for the most likely scenario of adoption of TELA maize variety. These are shown in Table 7. For example, the probability of a drought with no borer infestation in MASH in an average year is 0.07 which was calculated by multiplying the probability of drought (0.29), times the probability of no stemborer infestation (0.23). The same procedure was used to calculate the probabilities of the four events. The final average (expected) yield loss is the sum of the yield loss expected in each event weighted by the probability of occurrence of each event.

Table 7– Probability of drought and infestation of stemborer and yield reduction

	Probabilities			
	Drought	**Borer attack**	**No drought**	**No borer attack**
High-altitude (HA)	0.23	0.67	0.77	0.33
Mid-altitude sub-humid (MASH)	0.29	0.77	0.71	0.23
Mid-altitude moisture stress (MAMS)	0.33	0.57	0.67	0.43
Low-altitude sub-humid (LASH)	0.31	0.77	0.69	0.23
Low-altitude moisture stress (LAMS)	0.35	0.57	0.65	0.43

Source: Elaborated by authors

Output and Yields

The first step is to obtain the results for the year 2015-2016 and determine their correspondence to one of the four events in Table 7. The ESS3 includes a question on major causes of yield losses. A summary of the answers by administrative region is shown in Table 8. The major factor causing yield losses is the lack of rain, explaining more than 60 percent of yield losses in Amhara and Oromia, 75 percent in Tigray and 84 percent in SNNP.

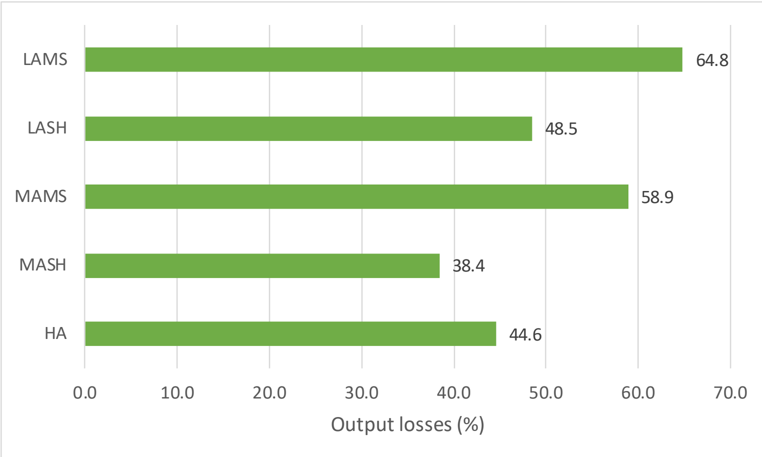
Table 8– Causes of yield damage on maize plots by region, percentage

	Tigray	Afar	Amhara	Oromia	Somali	Benish angul	SNNP	Gambella	Harari	Dire Dawa
Number of plots	(204)	(8)	(384)	(449)	(126)	(56)	(494)	(40)	(128)	(48)
Too much rain	1.0	0.0	5.5	6.5	0.0	1.8	3.2	5.0	0.0	0.0
Too little rain	74.0	12.5	63.5	61.3	96.8	25.0	84.2	72.5	96.1	100.0
Insects	3.9	0.0	3.1	3.8	0.8	3.6	2.0	0.0	3.9	0.0
Crop diseases	1.0	0.0	1.0	12.3	0.0	7.1	0.6	2.5	0.0	0.0
Weeds	2.5	12.5	1.3	0.7	0.0	17.9	0.8	7.5	0.0	0.0
Hail	9.8	12.5	5.5	1.1	0.0	0.0	2.4	0.0	0.0	0.0
Flood	0.5	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Frost	0.0	0.0	0.0	0.9	0.0	0.0	0.4	0.0	0.0	0.0
Wild animals	0.5	12.5	3.4	4.0	0.0	10.7	1.8	10.0	0.0	0.0
Birds	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Shortage of seed	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Depletion of soil fertility	4.4	0.0	0.5	4.2	0.0	10.7	2.4	0.0	0.0	0.0
Security problems	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Spoiled seeds	0.0	0.0	8.3	0.9	0.0	1.8	0.8	0.0	0.0	0.0
Other	2.5	50.0	6.5	3.8	2.4	21.4	1.2	2.5	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Authors based on CSA (2017)

Figure 8 shows the magnitude of production losses by maize production zone. According to households in ESS3, production losses went from 59 to 65 percent in moisture stressed zones, to 38 percent in MASH, with HA and LASH showing intermediate values (45 and 49 percent, respectively). With this evidence, we assume that our base year from ESS3 is a "drought year", or the "only drought" event in Table 7. Yields, production and costs from ESS3 are then assumed to be those of a drought year. To generate output in the "drought + borer" scenario we apply the probability of losses from stemborer attack in Table 7 to further reduce output of all households. For the two scenarios with no drought ("borer attack" and "no losses") we increase output of all households by the percentage of their claimed losses by drought according to ESS3 and shown in Figure 8. In the case of borer only, we reduce output by the percentage losses in Table 7 as before.

Figure 8– Magnitude of production losses by maize production zone, percentage



Source: Elaborated by authors based on CSA (2017)

Table 9 results of calculating the average output or yield of all individual events weighted by their respective probability, and a TELA maize-adoption scenario. This scenario assumes yields higher than in all other scenarios except of those in the no drought-no borer scenario. Notice that we assume no adoption of TELA maize in HA, so no output or yield are included for this maize production zone.

Table 9– Total output and yield for different scenarios, including adoption of TELA maize.

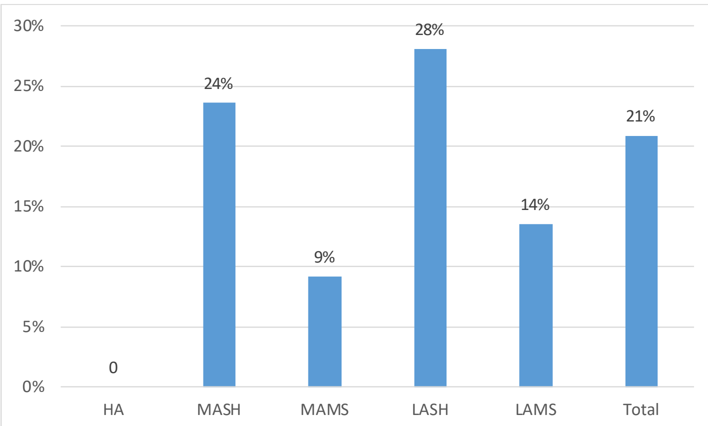
	HA	MASH	MAMS	LASH	LAMS
Output (000s tons)					
Drought	1,580	2,575	572	27	6
Stem borer	2,611	4,255	1,007	51	11
Drought + stemborer	1,201	1,957	463	21	4
No drought - no borer	3,435	5,598	1,244	68	14
Average (expected)	2,525	3,849	911	45	10
TELA maize adoption	-	4,759	995	57	11
Yield (tons/Ha)					
Drought	2.20	2.11	1.44	1.22	1.00
Stem borer	3.63	3.48	2.54	2.32	2.03
Drought + stemborer	1.67	1.60	1.17	0.93	0.81
No drought - no borer	4.77	4.58	3.14	3.05	2.51
Average (expected)	3.51	3.15	2.30	2.02	1.77
TELA maize adoption	-	3.89	2.51	2.59	2.01

Source: Elaborated by authors based on (CSA 2017).

Note: The average scenario results from calculating the average results of all events weighted by their respective probability. The TELA maize-adoption scenario assumes yields increasing to the levels of those in the no drought-no borer scenario. No adoption of TELA maize was assumed in the case of HA maize production zone.

Figure 9 shows the reduction in output losses that results from the adoption of the TELA maize variety compared to the expected scenario. The adoption of the new variety will result in an overall reduction of output losses of 21 percent with respect to the expected scenario, about 24 percent reduction of output losses in MASH and 28 percent in LASH.

Figure 9– Output increases that results from the adoption of the TELA maize variety, compared to output in the average scenario.



Source: Elaborated by authors based on ESS3.

Note: The average scenario results from calculating the average results of all events weighted by their respective probability. TELA maize-adoption scenario assumes yields increasing to the levels of those in the no drought-no borer scenario. No adoption of TELA maize was assumed in the case of HA production zone.

Costs

Costs of maize production are obtained from the ESS3. Average total and per hectare cost of maize production by maize production zone and for the different events (drought and borer attack) are presented in Table 10. We assumed that costs from ESS3 were the costs for the drought-only scenario. We modified costs of the other scenarios as follows. When no drought, we increased labor cost assuming that more work is needed for harvesting. In the case of stemborer attack, we increase cost of pesticide to match recommended doses. Still, we assume that higher use of pesticides is only effective to avoid higher losses than the ones shown in Figure 9. The TELA maize adoption scenario uses the same costs of the no-drought and no-borer scenario with higher seed cost. The final effect of adoption of the TELA maize variety on costs is relatively low as higher yields (output) associated to adoption of the new variety result in higher labor and seed costs.

Table 10– Total and per hectare cost of maize production for different scenarios including adoption of TELA maize

	HA	MASH	MAMS	LASH	LAMS
Total cost (mill. Birr)					
Drought	1,578	1,783	705	41	6
Stem borer	1,696	2,003	808	49	8
Drought + stemborer	1,692	1,988	804	48	8
No drought - no borer	1,582	1,798	709	42	6
Average (expected)	1,657	1,951	764	47	7
TELA maize adoption	-	1,830	733	44	6
Cost/Ha (Birr)					
Drought	1,305	1,116	1,057	713	714
Stem borer	1,475	1,306	1,240	913	868
Drought + stemborer	1,465	1,290	1,225	894	864
No drought - no borer	1,315	1,132	1,072	732	717
Average (expected)	1,420	1,261	1,163	866	802
TELA maize adoption	-	1,165	1,109	783	765

Source: Elaborated by authors based on ESS.

Note: The average scenario results from calculating the average costs of all events weighted by their respective probability. The TELA maize-adoption scenario assumes costs increasing to the levels of those in the no drought-no borer scenario. No adoption of TELA maize was assumed in the case of *HA*

Adoption

The ex ante adoption of the new TELA maize variety was estimated from the ESS3 using as dependent variable the adoption of improved maize varieties in 2015-2016. Table 11 shows the results of the maximum likelihood probit model. Looking at the factors affecting adoption in mid-altitude zones, we find that high precipitation variability, distance to market, tenure (parcel has land title), irrigation, age of household head, ownership of production assets, participation in food programs, and the cost of hired labor, all have significant effect on adoption. Results also show that households in arid areas in mid-altitude zones are less likely to adopt new varieties. Based on these results we expect that households closer to the market, with nonfarm income, higher assets, secured land tenure, with younger household heads, high number of household members and located in zones with average precipitation of bigger than 800 mm/year are more likely to adopt new varieties.

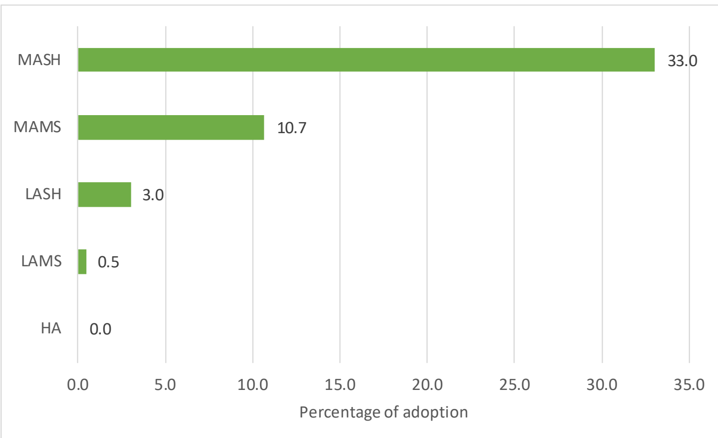
Table 11– Maximum Likelihood Probit estimates of the probability of adoption of improved maize seeds in Ethiopia

Explanatory Variables	Mid-altitude	High altitude	All Areas
Rainfall risk (rainfall variability indicator):			
Standard deviation of regional rainfall	0.001**	-0.001***	0
Market access and remoteness indicators			
Distance to all weather road	-0.005	-0.012***	-0.011***
Distance to market	-0.007***	-0.005***	-0.007***
Plot soil quality indicators and tenure security			
Plot distance from homestead	0.015	0.056**	-0.013
Plot slope	0.003	-0.043***	-0.023***
Parcel has land title	0.494***	0.028	0.236***
Parcel soil quality=fair	-0.061	-0.056	-0.019
Parcel soil quality= poor	0.154	-0.138	-0.087
Plot irrigated	0.913***	-0.382	0.251
Household poverty indicators:			
Nonfarm income	0.449*	-0.577***	-0.250**
House floor=Mud and cow dug	0.062	0.347*	0.196
Household productive assets indicators			
Own cart animal pushed	0.423	0.907***	0.849***
Own cart hand pushed	0.888**	-0.091	0.148
Human capital indicators			
Number of adult males	-0.052	-0.021	-0.064**
Number of adult females	-0.038	0.009	0.003
Female headed household	-0.003	0.043	-0.012
Age of household head	-0.009**	-0.001	-0.004*
Household size	0.041*	-0.011	0.006
Country humanitarian assistance programs			
Participates in food cash prog	0.815**	-0.068	0.198
Participates in free food program	-0.845***	-0.073	-0.558***
Participates in inputs for work program	(omitted)	-0.141	-0.215
Receives cash transfers	0.306	0.154	0.197*
Receives food transfers	-0.206	-0.182	-0.312*
Hired labor indicators			
Log value hired labor men	0.108***	0.109***	0.109***
Log value hired labor women	-0.032	0.177**	0.082*
Log value hired labor children	(omitted)	0.058	-0.11
Agroecology indicators			
Low precipitation= arid and semi-arid	-1.153***	-1.276***	-1.147***
Constant	-0.747	0.747***	0.199

Source: Elaborated by authors using data from CSA (2017)

Using the results of the econometric model together with individual household characteristics, we obtain the probability of adoption of the TELA maize variety by each household. Average probability of adoption by production zone is presented in Figure10. Households in moisture stress production zones are less likely to adopt the new variety. In mid-altitude production zones, sub-humid areas are 3 times more likely to adopt the new variety than moisture stress areas (33 and 10 percent of households adopting on average, respectively). In low-altitude zones, 3 percent households will adopt on average in sub-humid areas, six times more than in moisture stress areas (0.5 percent).

Figure 10– Average probability of adoption by production zone



Source: Elaborated by authors based on CSA (2017) data.

The adoption estimated with ESS3 data is used as a reference to capture differences between regions and as a lower bound of adoption as we expect adoption of TELA maize to be higher than the adoption of the regular improved varieties as it provides protection for stemborer and resistance to drought. We then use one standard deviation derived from the variation in the probability of adoption to determine a range of maximum, minimum and most likely using the average estimated adoption as the minimum adoption value instead of the expected adoption value. The interval of adoption for the different maize zones is shown in Table 12.

Table 12– Range for the percentage of adoption by zone

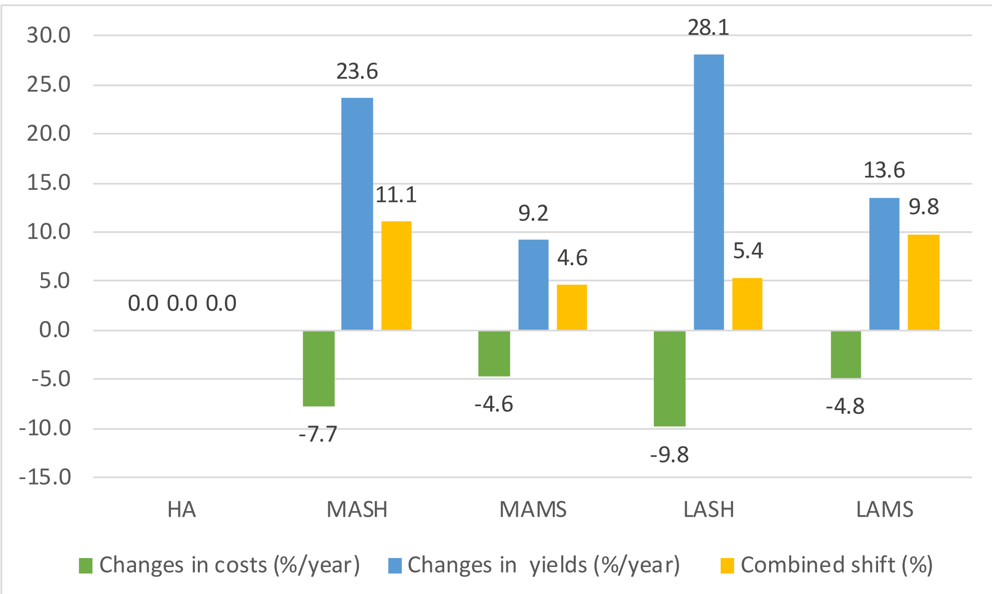
Maize zones		Lower bound	Expected	Upper bound
High-altitude	HA	-	-	-
Mid-altitude sub-humid	MASH	13.5	33.0	52.6
Mid-altitude moisture stress	MAMS	0.0	10.7	29.1
Low-altitude sub-humid	LASH	0.0	3.0	9.4
Low-altitude moisture stress	LAMS	0.0	0.5	1.4

Source: Elaborated by authors using ESS3 data

Changes in Output and Costs

Using the calculated probabilities and changes on yields and costs for different scenarios we determine changes in output and costs as the result of the adoption of TELA maize using the average scenario and the expected rate of adoption by production zone (Figure 11). Highest impacts are expected in sub-humid zones (MASH and LASH), with yield increases between 20 and 30 percent and cost decreases from 8 to 10 percent. .

Figure 11– Changes in output and costs as the result of adopting TELA maize relative to the average scenario and the expected rate of adoption by production zone, percentage.

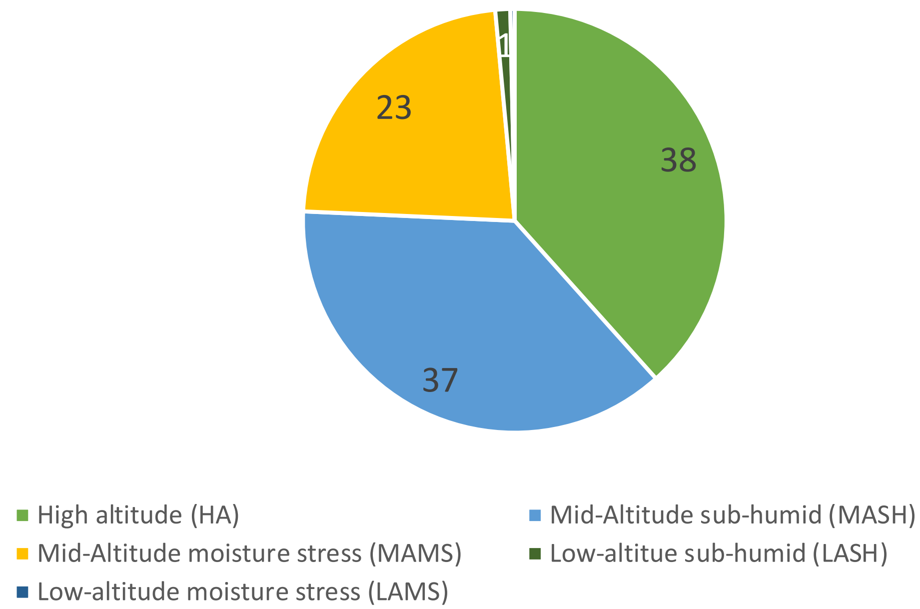


Source: Elaborated by authors

Consumption

Figure 12 shows the distribution of total consumption of maize by production zone, calculated using own-price and income elasticities (Table 13) together with consumption data from CSA (2017) and assuming that total output is consumed domestically. Own-price and income elasticities are also used to determine elasticities for the different zones in Table 13.

Figure 12– Share of maize consumption by production zone including rural and urban households, percentage



Source: Elaborated by authors based on EES

Table 13– Supply and demand elasticities for maize in different zones

	Supply	Demand [b]	
Maize zones	**Price elasticity of supply [a]**	**Own price elasticity**	**Income elasticity**
Mid-altitude - Arid	0.38	-0.73	0.77
Mid-altitude - Moisture stress	0.51	-0.73	0.75
Mid-altitude - Sub-humid	0.51	-0.72	0.78
High-altitude	0.51	-0.74	0.73
Lowlands	0.38	-0.72	0.78

Source: Elaborated by authors based on: (a) Alemu et al. (2003); (b) Berhane et al. (2011)

Table 14 summarizes the different parameters used in the estimations of the ESM and inputted into DREAMpy. While some parameters are common to all zones (base year, simulation years, discount rate and probability of success), most are disaggregated and were in many cases estimated at the zonal level, to account for differences in population growth for each zone and the adoption effects of TELA maize in these zones. All estimations and model runs were done using 2016 local currency units (birr). The exchange rate listed in Table 14 is the official exchange rate of that base year and was used to convert all estimations into US dollars.

Table 14– Key parameters and assumptions

Parameter	Unit	Zone					
		All	High-altitude (HA)	Low-altitude Moisture stress (LAMS)	Low altitude Sub-humid (LASH)	Mid-altitude Moisture stress (MAMS)	Mid-altitude Sub-humid (MASH)
Base year		2016					
Simulation years	Number	35					
Discount rate	%	10					
Exchange rate	ETB/USD	21.73					
Supply elasticity			0.51	0.38	0.38	0.51	0.51
Demand elasticity			-0.74	-0.72	-0.72	-0.73	-0.73
Supply growth	%/year		5.00	2.00	2.00	3.00	4.50
Demand growth	%/year		5.00	3.00	3.00	3.50	5.00
Cost change	%		0.00	-4.83	-9.77	-4.61	-7.67
Yield change	%		0.00	13.56	28.09	9.17	23.63
Prob. of R&D success	%	80.00					
Max adoption rate	%		0.00	0.47	3.01	10.67	33.04
Years to max adoption	Number		0	5	5	5	5

Source: Elaborated by authors using ESS3 data

6. RESULTS DISCUSSION

The results we present here are based on the data, econometric estimations, and assumptions detailed in the previous section and use the ESM modeled in DREAMpy, described in Section 4. We also present comparative results using the extreme values of key parameters obtained from the sensitivity analysis (for more information see the later subsection "Sensitivity Analysis"). To do this we use the combined upper limit of the yield and cost change distribution (K shift change) as well as the most optimistic maximum adoption to estimate what we label the "optimistic scenario," depicted in the infographic presented in Appendix B and produced and distributed before this paper was finalized.

Potential Welfare Effects of TELA maize Adoption

The results of the estimated present value of the benefits for producers and consumers of adopting TELA maize reflect the fact that the targeted area or this project is the mid altitude area. For this reason, 92 percent of the total estimated benefits of US$788 million is accrued in the MASH zone, as summarized in Table 15. The major beneficiaries are the producers of the MASH zone, with same gains for consumers in all zones, given the expected induced lower price.

Table 15– Benefits to consumers and producers—present value in million US dollars

Zone	Producer	Consumer	Total
High-altitude (HA)	-130.1	138.0	7.9
(max min scenarios)	*(-358.7 -15.6)*	*(392.3 16.3)*	*(33.6 0.7)*
Low-altitude Moisture stress (LAMS)	-0.3	0.8	0.6
(max min scenarios)	*(-.8 .1)*	*(2.4 .1)*	*(1.6 0.1)*
Low altitude Sub-humid (LASH)	-0.5	2.9	2.4
(max min scenarios)	*(1.5 -.2)*	*(8.2 .3)*	*(9.7 0.2)*
Mid-altitude Moisture stress (MAMS)	-13.2	62.9	49.7
(max min scenarios)	*(1.3 -3.9)*	*(179. 7.4)*	*(180.2 3.5)*
Mid-altitude Sub-humid (MASH)	653.8	134.3	788.1
(max min scenarios)	*(1,858.7 78.9)*	*(381.8 15.9)*	*(2,240.5 94.8)*
ALL	509.7	338.9	848.6
(max min scenarios)	*(1,502. 59.2)*	*(963.6 40.1)*	*(2,465.7 99.2)*

Source: Authors' summary based on DREAMpy simulations.

Note: Numbers are for the modeled scenario. We labelled numbers in parentheses and in italics as the optimistic (max) and pessimistic (min) scenarios. These scenarios use the modeled estimations and assumptions, except for having the highest (optimistic) and lowest (pessimistic) values for yield change and adoption.

Table 16 illustrates findings regarding the benefits accrued to different types of households based on the estimated probability of adoption. The total benefit of adoption equals ETB 1,292 per maize-producing household, which is equivalent to ETB 246 per person. If we consider only adopting households, adopters gain ETB 9,000 per household or ETB 1,705 per person. According to the results in Table 16, 30 percent of the total benefit of adoption of TELA maize will go to small-scale producers and 40 percent to self-sufficient producers. Surplus producers will get 30 percent of all benefits while representing only 25 percent of total producers. The benefit per hectare of maize (total area including area of nonadopters) is highest for small-scale producers (ETB 9,659); it is ETB 2,819 for surplus producers, while self-sufficient producers gain ETB 3,858.

Table 16– Benefits of adoption of TELA maize by type of producer

	Small-scale	**Self-sufficient**	**Surplus**	**Total**
Adopters and nonadopters				
Number of households (millions)	2.8	3.7	2.1	8.6
Number of household members (millions)	13	20	13	45.0
Adopters				
Probability of adoption	13.7	13.9	15.9	
Number of households (millions)	0.38	0.51	0.34	1.23
Number of household members (millions)	1.72	2.73	2.05	6.49
Benefits				
Benefits (millions of ETB)	3,354	4,391	3,331	11,076
Share in total benefits (%)	30	40	30	100
Benefits per household (all) (ETB)	1,202	1,198	1,571	1,292
Benefits per household member (all) (ETB)	268	224	258	246
Benefits per adopting household (ETB)	8,749	8,605	9,895	9,003
Benefits per person of adopting households (ETB)	1,952	1,609	1,626	1,705
Benefits per hectare of maize (ETB)	9,569	3,858	2,819	4,148

Source: Authors' elaboration based on ESS3.

Sensitivity Analysis

As we explain in the previous sections, the ex ante estimations summarized earlier in Table 15 rely on key parameters, some of which were estimated using ESS3, characteristics of maize production by defined zones, and, in some cases, expert opinions. Given the reliance of these estimations on predicted or estimated parameters, it is critical to identify how sensitive estimated benefits are to changes in the value of these different parameters. To assess the sensitivity of our results, we determine triangular probability distributions for each of the key parameters by defining a range of values (maximum and minimum values) around the expected value, between which we allow parameter values to vary.

The sensitivity analysis can be done for any of the estimated parameters, but to illustrate how sensitive these estimations are to variation, we use only the ones identified as most critical (listed in Table 17): yield change, cost change, and maximum adoption. The parameters *min* and *max* values listed in this table, used to generate the probability distribution, are the same parameters that we use to run the "pessimistic" and "optimistic" scenarios summarized in Appendix A.

Table 17– Parameter values used for sensitivity analysis, percentage

Parameter	Scenario	HA	LAMS	LASH	MAMS	MSH
Cost change	Estimated, "Most likely"	0.0	-4.8	-9.8	-4.6	-7.7
	Min, "Pessimistic"	0.0	-4.3	-6.7	-3.7	-7.3
	Max, "Optimistic"	0.0	-5.3	-12.9	-5.5	-8.0
Yield change	Estimated, "Most likely"	0.0	13.6	28.1	9.2	23.6
	Min, "Pessimistic"	0.0	5.7	-1.4	1.0	4.0
	Max, "Optimistic"	0.0	21.4	57.6	17.4	43.3
Max adoption	Estimated, "Most likely"	0.0	0.5	3.0	10.7	33.0
	Min, "Pessimistic"	0.0	0.0	0.0	0.0	13.5
	Max, "Optimistic"	0.0	1.4	9.4	29.1	52.6

Source: Authors' elaboration and estimations based on ESS3 and experts' opinions.

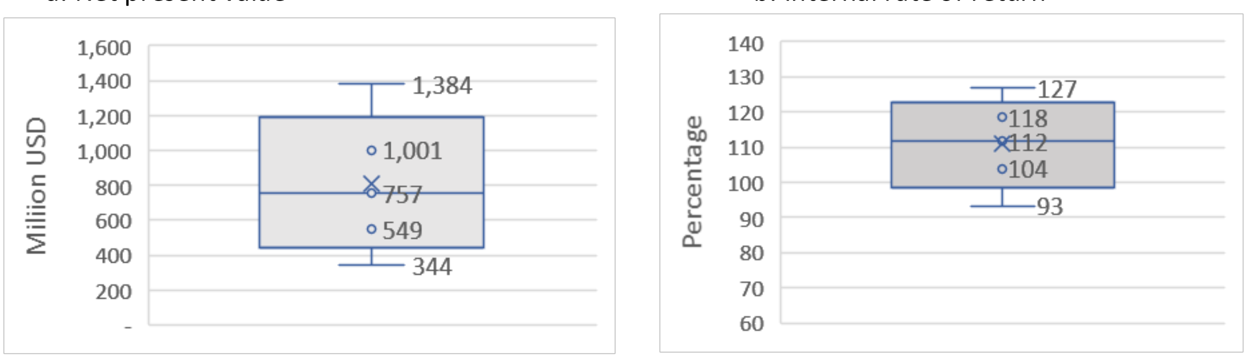
Input Variation

The size of the producer surplus is determined by the technology-induced vertical shift of the supply curve—given by a cost reduction, a yield increase, or the combination of both. The estimated benefits to consumers and producers estimations shown in Table 15 rely on inferences made from the ESS3 about the costs of production and yields from the "most likely" scenario and were estimated for each of the zones. The "most likely" value shown in Table 15 corresponds to the estimated mean value. The max and min values listed in this table were estimated using plus or minus one standard deviation from the estimated mean.

Using the statistical parameters and percentiles of the distributions obtained as explained above, Figure 13 illustrates the variation of benefits and internal rates of return (IRR) for the MASH zone where most benefits of the TELA maize are accrued due to variations in the estimated changes in yields, costs and maximum adoption listed in Table 17. The median of the estimated distribution for NPV and the IRR are unsurprisingly, very close to the "most likely" estimate presented in Table 16, with interquartile range equally distributed around that median. To illustrate the variability of these estimates we use the values generated for MASH, the most important zone in terms of production and potential of adoption of the TELA maize variety. Given the parameters of the distribution generated, Figure 13 shows that for the MASH zone, there is a probability of 0.75 of obtaining net benefits above $549 million.

Figure 13– TELA maize: NPV and IRR sensitivity due to changes in input variables, MASH zone

a. Net present value b. Internal rate of return



Source: Authors' elaboration based on DREAMpy simulations.
Note: Placement horizontally and the widths of the interquartile ranges displayed is arbitrary, but numbers displayed correspond to the 5, 25, 50 , 75, and 95 percentiles of the generated distribution.

Cost of TELA Maize Adoption Delay

One of the key assumptions on the estimation of the producer and consumers gains is the year when the flow of estimated benefits will start, which is the year when farmers will start planting the TELA maize, or first adoption year. The estimated total benefits of $848 listed in Table 15 assume that the TELA maize will be first planted in 2023, which is the target date for the TELA project. Since all benefits are discounted at an annual rate of 10 percent (as listed in Table 14), delays will have a compound effect over the annual estimated benefits. Delaying the adoption of TELA maize from 2023 to 2028 will yield a reduction of 30 percent of the total estimated benefits, as shown in Table 18.

Table 18– Cost of a five-year regulatory delay

Zone	First adoption year	Unit	Estimated benefits		
			Producers	Consumers	Total
High-altitude	2023	USD, mill	-130.1	138.0	7.9
(HA)	2028	USD, mill	-91.5	96.9	5.4
		Loss, %		29.8	31.2
Low-altitude Moisture stress	2023	USD, mill	-0.3	0.8	0.6
(LAMS)	2028	USD, mill	-0.2	0.6	0.4
		Loss, %		34.4	33.3
Low altitude Sub-humid	2023	USD, mill	-0.5	2.9	2.4
(LASH)	2028	USD, mill	-0.3	1.9	1.6
		Loss, %		34.4	33.9
Mid-altitude Moisture stress	2023	USD, mill	-13.2	62.9	49.7
(MAMS)	2028	USD, mill	-8.6	42.0	33.3
		% loss		33.3	32.9
Mid-altitude Sub-humid	2023	USD, mill	653.8	134.3	788.1
(MASH)	2028	USD, mill	453.0	94.3	547.3
		Loss, %	30.7	29.8	30.6
All	2023	USD, mill	509.7	338.9	848.6
	2028	USD, mill	352.4	235.6	588.0
		Loss, %	30.9	30.5	30.7

Source: Authors' elaboration based on DREAMpy simulations.

Losses to producers will be incurred in the mid-altitude zones, where the TELA maize will be adopted. In the other zones, producers will not be affected by this delay, since these areas are not targeted areas of TELA project. On the contrary, as shown in Table 18, producers in these zones will register lower losses with a delay in the adoption of TELA maize, given that the price reduction induced by the technology change will be in effect 5 years later. The reduction in consumers benefits will affect all zones, as these price reductions, observed by all consumers, will only start 5 years later.

7. CONCLUSION AND RECOMMENDATIONS

The potential benefits for TELA maize to producers and consumers in Ethiopia are estimated using household disaggregated data, along with secondary data, and informed experts' opinion. The use of disaggregated household data made it possible to estimate the different maize production zones, classified according to altitude and rainfall. In addition, the household data was used to estimate parameters, such as adoption, change in costs, and insecticide use, as well as the probability of drought and stemborer infestation. These estimations are critical for assessing the potential benefits of TELA maize since the gains will be accrued from the expected protection against a combination of stemborers and drought, which in turn will result in an increased production through higher yields and revenues for producers and lower prices for consumers.

The estimations use an economic surplus partial equilibrium model run with the newly developed DREAMpy software. The estimations show that if the drought tolerant and insect resistant TELA maize is planted in 2023, the net present-value benefits for producers and consumers would be around $850 million. Given that the targeted area of TELA maize is the mid-altitude zone, the analysis shows that most of the benefits will be accrued by producers in this maize zone. Consumers from all maize zones will benefit via the projected reduction in prices.

Using an official social discount rate of 10 percent, we estimate that if the adoption of this new technology is delayed by 5 years the benefits will fall by 30 percent. These costs underscore the importance of having an enabling policy environment and regulatory system — covering biosafety and food/feed safety assessment, and varietal release registration — that is efficient, predictable, and transparent and ensures that the projected economic benefits are realized.

To ensure that such system is in place that would review the proposed release in a timely manner, the implementation of specific policies would need to be considered and implemented as follows.

- Regulatory framework:
    - The Environment, Forest and Climate Change Commission (EFCCC)needs to ensure full implementation of the biosafety framework, through the Biosafety Proclamation, as amended in 2015, and the Regulation to establish the National Biosafety Advisory Committee (NBAC). The appointment of NBAC was confirmed in early 2020; it will now be essential to ensure its members are inducted and meeting on a regular basis.

    - The Ethiopian biosafety regulatory system needs adequate financial and scientific resources to conduct the review and subsequent decision-making of all submitted applications in a predictable, transparent, and timely manner.
    - TELA maize will need to obtain biosafety approval for general release from EFCCC. EFCCC should coordinate its approval process with other relevant Ministries and authorities (such as the Ministry of Agriculture and the National Codex Commission) so the approval process includes a determination of safety not only for environmental issues but also food and feed safety issues.
    - In the approval process, EFCCC and the other relevant government ministries should consider not only a properly conducted scientific risk assessment but also the potential benefits of adopting TELA maize set forth in this analysis as well as other possible impacts (such as the reduction in pesticide use's positive impact on farmer health and on the environment). A more comprehensive and more informed decision can be arrived at when the full range of potential impacts – both positive and negative – are included in the decision-making process.
    - In addition to biosafety approval, other regulatory steps, such as plant varietal registration, will be required before farmers can grow TELA maize. The GM crop developer should work with EFCCC and the regulatory officials in charge of plant varietal registration to coordinate those two government approval processes to streamline the time it takes for the product to be given to farmers. This could include setting forth procedures so that information obtained from confined field trials and other research experiments can be utilized for both biosafety approval and variety registration. This approach was adopted during the registration of GM, insect-resistant cotton in Ethiopia and could be formalized through a joint guideline.
    - As Ethiopia moves toward the commercial release of GM food crops, numerous regulatory policies and guidelines to implement the amended Biosafety Proclamation have been developed. One provision which has not been fully addressed is the need for a public consultation process that accompanies final regulatory decision-making.
- Stewardship and outreach:
    - Introduction of TELA maize will require a stewardship plan in order to ensure technology effectiveness and product quality. A key component of such stewardship is an Insect

Resistance Management (IRM) plan; this will rely to a large extent on farmers' compliance, e.g., for planting 'refuges' of conventional maize.

- AATF have taken the lead in defining a stewardship strategy in all TELA maize partner countries. In Ethiopia, some stewardship experience was gained around the introduction of insect-resistant cotton. Important lessons can be learned from this prior experience in order to deepen and expand local stewardship capacity.
- While tailoring a stewardship program in Ethiopia, it will be critical to work with the local maize value chain (public / private) and particularly with farmers. Collaboration with local stakeholders will foster compliance. Special attention needs to be given to small-scale farmers, who stand to benefit from the introduction of TELA maize, and who often have limited resources to effectively implement stewardship / IRM measures.

8. REFERENCES

Abate, T., B. Shiferaw, A. Menkir, D. Wegary, Y. Kebede, K. Tesfaye, M. Kassie, G. Bogale, B. Tadesse, T. Keno. 2015. "Factors that transformed maize productivity in Ethiopia." *Food Security* 7: 965–981

Abera, K.; O. Crespo; J. Seid; F. Mequanent. 2018. "Simulating the impact of climate change on maize production in Ethiopia, East Africa." *Environmental Systems Research* 7(1):4.

Adefris, T., Dagne, W., Abraham, T., Birhanu, T., Kassahun, B., Dennis, F. and Prasanna, B.M. 2015. Quality Protein Maize (QPM): A guide to the technology and its promotion in Ethiopia. Addis Ababa: CIMMYT.

Alemu ZG, K Oosthuizen & HD van Schalkwyk. 2003. "Grain-Supply Response in Ethiopia: An Error-Correction Approach." *Agrekon* 42:4.

Alston, J M, G W Norton, and P G Pardey. 1995. Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting. Cornell University Press.

Assefa Gebre-Amlak. 1985." Survey of lepidopterous stemborers attacking maize and sorghum in Ethiopia." *Ethiopian Journal of Agricultural Science* 7: 15.

Bartel P., and J. Muller. 2007. Horn of Africa natural hazard probability and risk analysis. U.S. Department of State Humanitarian Information Unit. Available on line at https://reliefweb.int/sites/reliefweb.int/files/resources/08E06D83D1F98F3E85257309005091A1-Full_Report.pdf

Berhane G., Z. Paulos, K. Tafere, and S. Tamiru. 2011. "Foodgrain Consumption and Calorie Intake Patterns in Ethiopia." ESSP II Working Paper No. 23, Ethiopia Strategy Support Program II.

Berhanu Gebremedhin, Fernandez-Rivera S, Mohammed Hassena, Mwangi W and Seid Ahmed. 2007. Maize and livestock: Their inter-linked roles in meeting human needs in Ethiopia (SNNPR, Oromiya and Amhara Regions) Research Report 6. ILRI (International Livestock Research Institute), Nairobi, Kenya. 103 pp.

Chilot Yirga, Dawit Alemu., Leonard Oruko, Kefyalew Negisho and Greg Taxler. 2016. Tracking the Diffusion of Crop Varieties Using DNA Fingerprinting. Research Report 112. EIAR, Addis Ababa, Ethiopia.

CSA – Central Statistical Agency of Ethiopia. Ethiopia Socioeconomic Survey, Wave 3 (**ESS3**) 2015-2016. Public Use Dataset. Ref: ETH_2015_ESS_v02_M. https://microdata.worldbank.org/index.php/catalog/2783

CSA – Central Statistical Agency of Ethiopia. 1996. Agricultural Sample Survey 1995/1996. Report on area and production for major crops. The Federal Democratic Republic of Ethiopia. Central Statistical Agency, June, Addis Ababa.

Central Statistical Agency of Ethiopia. 2014. Report on Crop and livestock product Utilization (Volume VII). The Federal Democratic Republic of Ethiopia. Central Statistical Agency, September 2014, Addis Ababa

CSA – Central Statistical Agency. 2016a. Agricultural Sample Survey 2015/2016 (2008 E.C.) Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season)Volume I, Statistical Bulletin 584, Addis Ababa.

CSA – Central Statistical Agency (CSA) 2016b. Agricultural Sample Survey 2015/2016 (2008 E.C.) Report on Area, Production and Farm Management Practice of Belg Season for Private Peasant Holdings. Volume V, Statistical Bulletin 578, Addis Ababa.

CSA – Central Statistical Agency of Ethiopia. 2017. Ethiopia Socioeconomic Survey, Wave 3 2015-2016. [Data file]. Retrieved from: https://microdata.worldbank.org/index.php/catalog/2783

CSA - Central Statistical Agency of Ethiopia. 2018. Agricultural Sample Survey 2017/18 (2010 E.C.). Volume I, Report on area and production of major crops (private peasant holdings, meher season)

Conway, D. and E. L. F. Schipper. 2011. “Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia.” *Global Environmental Change* 21(1): 227-237

de Groote, H., Chilot Yirga, Moti Jaleta, Zachary M.G., Nipula G., and Kidist Gebreselassie. 2014. Baseline Survey: Nutritious Maize for Ethiopia (NuME). Research Report 102. EIAR, Addis Ababa, Ethiopia.

EATA - Ethiopian Agricultural Transformation Agency. 2014. Transforming agriculture in Ethiopia: Annual report 2013/2014. Addis Ababa, Ethiopia. 94pp.

EARO. 2000. Research Strategy for Maize. Ethiopian Agricultural Research Organization (EARO), Addis Ababa, Ethiopia.

Emana Getu, Abraham Tadesse, Mulugeta Negeri, Tadele Tefera, Hadush Tsaheye and Asmare Dejene (2008). Review of Entomological Research on Maize, Sorghum and Millet. In: Abraham Tadesse (ed.). 2008. Increasing Crop Production through Improved Plant Protection – Volume I. Plant Protection Society of Ethiopia (PPSE), 19-22 December 2006. Addis Ababa, Ethiopia. PPSE and EIAR, Addis Ababa, Ethiopia. 598 pp.

Emana Getu. 2002. Ecological analyses of cereal stemborers and their natural enemies under maize and sorghum based agro-ecosystems in Ethiopia. Ph. D Dissertation, Kenyatta University.

Ethiopian Institute of Agricultural Research (EIAR). 2017. Cereals Research Strategy: 2016-2030. Addis Ababa. Ethiopia.

FAO. 2020. Food and Agriculture Organization of the United Nations, FAOSTAT [Data file]. Yield calculated as the ratio of crop output and area harvested of the crop. FAOSTAT. Retrieved from http://www.fao.org/faostat/en/#data

FDRE-MoARD - Federal Democratic Republic of Ethiopia-Ministry of Agriculture and Rural Development. 2010. Agricultural Growth Program (AGP) Program Implementation Manual. Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia. 132pp.

Gemechu, F., Santiago, D. R., & Sori, W. 2013. “Laboratory evaluation of cotton (*Gossypium hirsutum*) and Ethiopian mustard (*Brassica cariata*) seed oils as grain protectants against maize weevil, *Sitophilus zeamais* M.(Coleoptera: Curculionidae)”. *Afr. J. Agric. Res* 8(32), 4374-4379.

Getachew Legese, M. Jaleta, A. Langyintuo, W. Mwangi and R. La Rovere. 2010. Characterization of maize producing households in Adami Tulu - Gido Kombolcha and Adama districts in Ethiopia. Country Report – Ethiopia. Nairobi: CIMMYT.

Goftishu, M.; Y. Assefa; A. Niba and C. Fininsa. 2017. “Cereal stem borer management practices in subsistence farms of eastern Ethiopia.” *International Journal of Pest Management* 63(4): 4.

Jaleta, M., Yirga, C., Kassie, M., de Groote, H., & Shiferaw, B. (2013). *Knowledge, adoption and use intensity of improved maize technologies in Ethiopia*. 2013 Fourth International Conference, September 22-25, 2013, Hammamet, Tunisia 161483, African Association of Agricultural Economists (AAAE).

Jaleta, M., Marenya, P., & Beshir, B. (2018). Does crop diversification reduce downside risk in maize yield enhancing investments? Evidence from Ethiopia using panel data. Paper presented at the International Conference of Agricultural Economists , July 28- August 3, 2018, Vancouver, Canada. http://dx.doi.org/10.22004/ag.econ.277217.

Juhar, H. M. and T. Semere. 2017. "Status, challenges and future role of modern biotechnology in Ethiopia: A review." *Journal of the Drylands* 7(1): 617-632.

Keno, T., G. Azmach, D. Wegary, M. Worku, B. Tadesse, L. Wolde, T. Deressa, B. Abebe, T. Chibsa, and L. M. Suresh. 2018. "Major biotic maize production stresses in Ethiopia and their management through host resistanct." *African Journal of Agricultural Research* 13(21): 1042-1052.

Leta Tulu, Mosisa Worku, Gelana Seboksa, Jemal Abdurehman, Hadji Tuna, Sewagegne Tariku and S. Twumasi-Afriyie 2002. Quality Protein Maize Research In Ethiopia In Ethiopia 2002. In: Mandefro Nigussie, D. Tanner, and S. Twumasi-Afriyie (eds.). 2002. Enhancing the Contribution of Maize to Food Security in Ethiopia: Proceedings of the Second National Maize Workshop of Ethiopia, 12-16 November 2001, Addis Ababa, Ethiopia: Ethiopian Agricultural Research Organization (EARO) and International Maize and Wheat Improvement Center (CIMMYT).

MoA, 2012. Crop Diversity Register. Issue No. 15. Ministry of Agriculture, Animal and Plant Health Regulatory Directorate. June 2012, Addis Ababa.

Mwalusepo, S.; H. E. Z. Tonnang; E. S. Massawe; G. O. Okuku; N. Khadioli; T. Johansson; P. A. Calatayud; and B. P. Le Ru. 2015. "Predicting the Impact of Temperature Change on the Future Distribution of Maize Stem Borers and Their Natural Enemies along East African Mountain Gradients Using Phenology Models. *PLoS One* 10(6): e0130427.

National Planning Commission. 2017. Ethiopia's Progress Towards Eradicating Poverty. An Interim Report on 2015/16 Poverty Analysis Study. Federal Democratic Republic Of Ethiopia. http://www.csa.gov.et/ehioinfo-internal?download=899:2016-poverty-interim-report-1&start=30

Rashid, S. and Dorosh, P.A. 2012. Food and Agriculture in Ethiopia. University of Pennsylvania Press Philadelphia. Available at: http://publication.eiar.gov.et:8080/xmlui/bitstream/handle/123456789/224/Food%20and%20Agriculture%20in%20Ethiopia.pdf?sequence=1&isAllowed=y

Twumasi-Afriyie S., Habtamu Zelleke, Kassa Yihun, Bayisa Asefa and Sewagegne Tariku 2002. Development and Improvement of Highland Maize in Ethiopia 2002. In: Mandefro Nigussie, D. Tanner, and S. Twumasi-Afriyie (eds.). 2002. Enhancing the Contribution of Maize to Food Security in Ethiopia: Proceedings of the Second National Maize Workshop of Ethiopia, 12-16 November 2001, Addis Ababa, Ethiopia. Addis Ababa, Ethiopia: Ethiopian Agricultural Research Organization (EARO) and International Maize and Wheat Improvement Center (CIMMYT).

Verkaart, Simone, Kai Mausch, Lieven Claessens, and Ken E. Giller. 2019. "A recipe for success? Learning from the rapid adoption of improved chickpea varieties in Ethiopia." *International Journal of Agricultural Sustainability* 17(1): 34-48.

Wamatsembe, I.M., Asea, G. and Haefele, S.M. 2017. "A survey: potential impact of genetically modified maize tolerant to drought or resistant to stem borers in Uganda". *Agronomy* 7(1), p.24.

Worku, M.; S. Twumasi Afriyie; W. Legesse; E, Berhanu Tadesse; G. Demisie; G. Bogale.; G. Dagne Wegary; B. M. Prasanna. 2012. Meeting the challenges of global climate change and food security through innovative maize research. Third National Maize Workshop of Ethiopia; Addis Ababa, Ethiopia; April 18–20, 2011. CIMMYT.

World Bank. 2020a. The World Bank, World Development Indicators. GDP (constant 2010 U$S) [Data file]. Retrieved from https://data.worldbank.org/country/ethiopia

World Bank. 2020b. The World Bank, World Development Indicators. Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population [Data file]. https://data.worldbank.org/country/ethiopia

Zaidi, P.H., 2019. Management of drought stress in field phenotyping. CIMMYT, Mexico. Available at https://repository.cimmyt.org/bitstream/handle/10883/19998/60167.pdf

APPENDIX A SUMMARY DREAMpy RUNS

Table B1 Input for all scenarios

Maize production zones	Production	Consumption	Price	Supply Elasticity	Demand Elasticity	Supply Growth	Demand Growth
	(1000 mt)	(1000 mt)	1000 ETB/mt			%/year	%/year
High-altitude (HA)	2575.27	2675.71	4.06	0.51	-0.74	5.00	5.00
Low-altitude Moisture stress (LAMS)	9.84	23.28	3.73	0.38	-0.72	2.00	3.00
Low altitude Sub-humid (LASH)	45.18	79.55	3.90	0.38	-0.72	2.00	3.00
Mid-altitude Moisture stress (MAMS)	913.87	1590.96	3.79	0.51	-0.73	3.00	3.50
Mid-altitude Sub-humid (MASH)	3855.77	2603.39	3.96	0.51	-0.73	4.50	5.00

Source: Production, consumption, and price are authors' calculations using …

Table B2 Scenarios summary, main changes due to expected cost and yield changes, and technology adoption rate

Scenario	Maize production zones	Cost change (%)	Yield change (%)	Adoption rate (%)
Most Likely	High-altitude (HA)	0.00	0.00	0.00
	Low-altitude Moisture stress (LAMS)	-4.83	13.56	0.47
	Low altitude Sub-humid (LASH)	-9.77	28.09	3.01
	Mid-altitude Moisture stress (MAMS)	-4.61	9.17	10.67
	Mid-altitude Sub-humid (MASH)	-7.67	23.63	33.04
Optimistic	High-altitude (HA)	0.00	0.00	0.00
	Low-altitude Moisture stress (LAMS)	-5.32	21.41	1.42
	Low altitude Sub-humid (LASH)	-12.86	57.62	9.43
	Mid-altitude Moisture stress (MAMS)	-5.50	17.39	29.10
	Mid-altitude Sub-humid (MASH)	-7.99	43.28	52.60
Pessimistic	High-altitude (HA)	0.00	0.00	0.00
	Low-altitude Moisture stress (LAMS)	-4.35	5.72	0.00
	Low altitude Sub-humid (LASH)	-6.68	-1.43	0.00
	Mid-altitude Moisture stress (MAMS)	-3.72	0.95	0.00
	Mid-altitude Sub-humid (MASH)	-7.35	3.98	13.49

Source: Authors using information provided by farmers, scientists and industry experts.

Table B3 Results for most likely scenario

	High-altitude (HA)	Low-altitude Moisture stress (LAMS)	Low altitude Sub-humid (LASH)	Mid-altitude Moisture stress (MAMS)	Mid-altitude Sub-humid (MASH)	Total
Producers' Benefits, Present value (PV), US$ mill.	-130.13	-0.28	-0.49	-13.19	653.79	509.69
Consumers' Benefits, PV, US$ mill.	138.01	0.84	2.88	62.88	134.30	338.91
Total Benefits, PV, US$ mill.	7.88	0.56	2.38	49.68	788.09	848.61
Cost of Research, US$ mill.	0.00	0.14	0.15	0.35	1.00	1.65
Net Present value (NPV), US$ mill.	7.88	0.42	2.23	49.34	787.09	846.96
Benefit/Cost, Ratio	--.--	3.90	15.67	143.56	785.99	515.78
Internal Rate of Return (IRR), percentage	--.--	22.80	40.25	77.08	112.53	102.82

Source: Authors' estimation using DREAMpy.

Table B4 Results for most likely scenario + five years R&D

	High-altitude (HA)	Low-altitude Moisture stress (LAMS)	Low altitude Sub-humid (LASH)	Mid-altitude Moisture stress (MAMS)	Mid-altitude Sub-humid (MASH)	Total
Producers' Benefits, Present value (PV), US$ mill.	-91.45	-0.18	-0.31	-8.64	453.02	352.44
Consumers' Benefits, PV, US$ mill.	96.88	0.55	1.89	41.97	94.27	235.56
Total Benefits, PV, US$ mill.	5.42	0.38	1.58	33.33	547.29	588.00
Cost of Research, US$ mill.	0.00	0.14	0.15	0.34	1.00	1.63
Net Present value (NPV), US$ mill.	5.42	0.23	1.43	32.99	546.29	586.37
Benefit/Cost, Ratio	--.--	2.65	10.55	97.10	547.40	359.88
Internal Rate of Return (IRR), percentage	--.--	16.72	26.91	46.62	64.56	59.89

Source: Authors' estimation using DREAMpy.

Table B5 Results for optimistic scenario

	High-altitude (HA)	Low-altitude Moisture stress (LAMS)	Low altitude Sub-humid (LASH)	Mid-altitude Moisture stress (MAMS)	Mid-altitude Sub-humid (MASH)	Total
Producers' Benefits, Present value (PV), US$ mill.	-358.71	-0.75	1.50	1.25	1858.74	1502.04
Consumers' Benefits, PV, US$ mill.	392.26	2.40	8.19	178.97	381.80	963.62
Total Benefits, PV, US$ mill.	33.56	1.65	9.69	180.22	2240.54	2465.66
Cost of Research, US$ mill.	0.00	0.14	0.15	0.35	1.00	1.65
Net Present value (NPV), US$ mill.	33.56	1.50	9.54	179.87	2239.54	2464.01
Benefit/Cost, Ratio	--.--	11.42	63.65	520.73	2234.58	1498.61
Internal Rate of Return (IRR), percentage	--.--	35.69	63.28	105.28	139.71	129.24

Source: Authors' estimation using DREAMpy.

Table B6 Results for optimistic scenario + five years R&D

	High-altitude (HA)	Low-altitude Moisture stress (LAMS)	Low altitude Sub-humid (LASH)	Mid-altitude Moisture stress (MAMS)	Mid-altitude Sub-humid (MASH)	Total
Producers' Benefits, Present value (PV), US$ mill.	-251.88	-0.47	0.96	1.00	1288.12	1037.72
Consumers' Benefits, PV, US$ mill.	275.05	1.57	5.36	119.31	267.71	669.00
Total Benefits, PV, US$ mill.	23.16	1.10	6.32	120.31	1555.83	1706.72
Cost of Research, US$ mill.	0.00	0.14	0.15	0.34	1.00	1.63
Net Present value (NPV), US$ mill.	23.16	0.96	6.17	119.97	1554.83	1705.09
Benefit/Cost, Ratio	--.--	7.75	42.32	350.52	1556.12	1044.59
Internal Rate of Return (IRR), percentage	--.--	24.44	39.10	60.38	77.16	72.34

Source: Authors' estimation using DREAMpy.

Table B7 Results for pessimistic scenario

	High-altitude (HA)	Low-altitude Moisture stress (LAMS)	Low altitude Sub-humid (LASH)	Mid-altitude Moisture stress (MAMS)	Mid-altitude Sub-humid (MASH)	Total
Producers' Benefits, Present value (PV), US$ mill.	-15.63	-0.04	-0.16	-3.89	78.87	59.16
Consumers' Benefits, PV, US$ mill.	16.33	0.10	0.34	7.43	15.89	40.09
Total Benefits, PV, US$ mill.	0.70	0.06	0.18	3.55	94.76	99.25
Cost of Research, US$ mill.	0.00	0.14	0.15	0.35	1.00	1.65
Net Present value (NPV), US$ mill.	0.70	-0.08	0.03	3.20	93.76	97.60
Benefit/Cost, Ratio	--.--	0.45	1.17	10.25	94.51	60.32
Internal Rate of Return (IRR), percentage	--.--	5.30	11.88	33.53	67.32	59.53

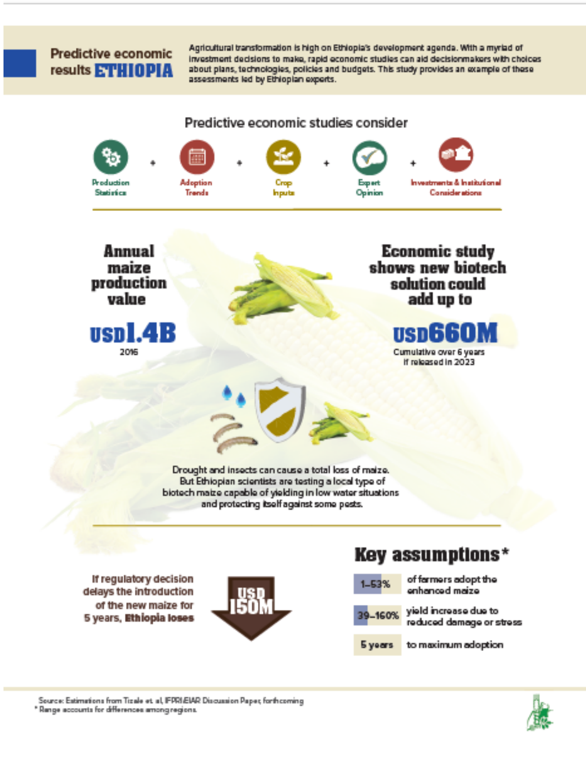
Source: Authors' estimation using DREAMpy.

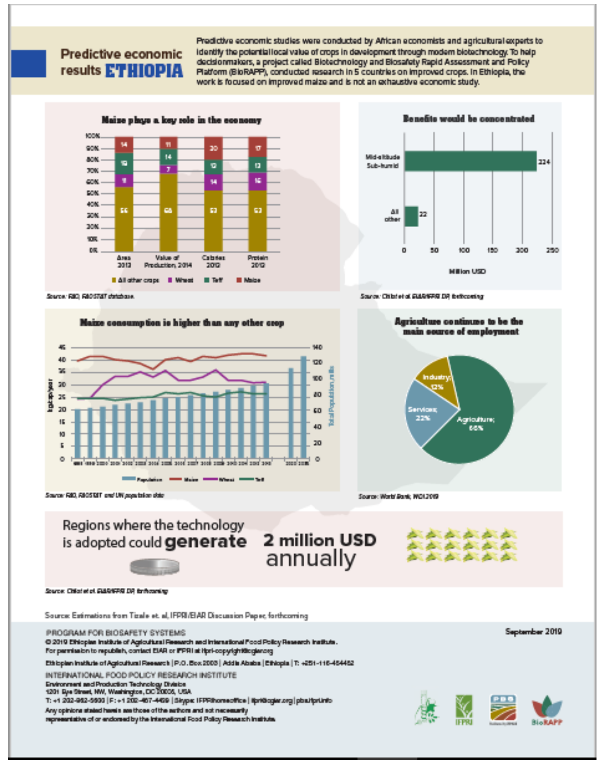
Table B8 Results for pessimistic scenario + five years R&D

	High-altitude (HA)	Low-altitude Moisture stress (LAMS)	Low altitude Sub-humid (LASH)	Mid-altitude Moisture stress (MAMS)	Mid-altitude Sub-humid (MASH)	Total
Producers' Benefits, Present value (PV), US$ mill.	-11.00	-0.02	-0.10	-2.56	54.64	40.96
Consumers' Benefits, PV, US$ mill.	11.48	0.07	0.22	4.97	11.17	27.90
Total Benefits, PV, US$ mill.	0.48	0.04	0.12	2.41	65.80	68.86
Cost of Research, US$ mill.	0.00	0.14	0.15	0.34	1.00	1.63
Net Present value (NPV), US$ mill.	0.48	-0.10	-0.03	2.07	64.80	67.23
Benefit/Cost, Ratio	--.--	0.30	0.81	7.03	65.82	42.14
Internal Rate of Return (IRR), percentage	--.--	4.02	9.34	23.45	42.18	38.09

Source: Authors' estimation using DREAMpy.

APPENDIX B INFOGRAPHIC: OPTIMISTIC SCENARIO





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