African Journal of Agricultural and Resource Economics Volume 12 Number 2 pages 174-187

Sorghum research and poverty reduction in the presence of trade distortions in Ethiopia

Weldensie Embaye*
Department of Agricultural Economics, Kansas State University, Manhattan KS. E-mail: wembaye@ksu.edu

Nathan Hendricks
Department of Agricultural Economics, Kansas State University, Manhattan KS. E-mail: nph@ksu.edu

Nina Lilja
Department of Agricultural Economics, Kansas State University, Manhattan KS. E-mail: nlilja@ksu.edu

* Corresponding author

Abstract

This research was conducted to evaluate the impact of innovations to improve the yield and nutrition of sorghum varieties in Ethiopia. Importantly, we used an economic model to account for the market impacts of the innovation. Household data on the previous adoption of improved varieties were used to assess the likely impact on individual households and on overall poverty reduction. Our study also accounts for trade distortions in the market. Sorghum prices in Ethiopia are depressed by trade policies such as export restrictions, product subsidies and food aid, similar to agricultural commodities in many other developing countries. We considered the example of a current programme focused on sorghum innovation and estimate an expected rate of return of about 21%. Our results also indicate that the benefits of the programme would be larger if trade distortions were eliminated.

Key words: sorghum innovation; equilibrium displacement model; trade distortions; poverty impact; Ethiopia

1. Introduction

Sorghum is one of the most important staple foods for millions of poor rural people in the semiarid tropics. Sorghum grows in harsh environments where other crops do not grow well, and it is usually grown with little or no application of fertilisers or other inputs by smallholder farmers. During an unfavourable growing season, sorghum is the only crop that can save the poor from starvation (Ahmed *et al.* 2000). It is the fifth most important cereal crop grown in the world, and the second most important cereal crop grown in Africa (Fetene *et al.* 2011). However, compared to other cereals, less attention is given to sorghum development.

Sorghum development has good potential to increase income levels and reduce poverty, particularly in Africa, where many areas are dominantly arid and where food insecurity and malnutrition are prevalent. Sorghum is also the best alternative to barley for the beer-brewing industry in Africa (Clover 2003). Given the economic importance of sorghum in food and feed, as well as malt and beverage production, development agencies are investing in varietal development efforts to increase the productivity and the nutritional value of the crop. Taylor (2003) asserts that sorghum research and development is crucial to unleash sorghum potential on food security in Africa.

With this research, we estimate the aggregate welfare impacts of sorghum research and development (R&D), as well as estimate the effectiveness of R&D in reducing poverty. To do so, it is important to model the market response to innovations. Increasing sorghum productivity that ultimately increases supply may also decrease the price, which partly will offset the increase in income from increased productivity. Government policies can also affect the impacts of innovations. In developing countries, governmental interventions are often documented as anti-agricultural – agricultural policies favour consumers at the expense of producers (Byerlee & Sain 1986; Anderson 2010). Anderson (2010) argues that developing countries' policies reduce national welfare and increase inequality and poverty, as farm households are poorer relative to non-farm households on average. These distortions also affect the size and distribution of agricultural research benefits (Alston *et al*. 1988).

There are several ways to evaluate research benefits. Econometric methods are often used for ex-post research evaluation (Alston *et al*. 2002; Alene & Coulibaly 2009; Becerril & Abdulai 2010; Shiferaw *et al.* 2014) but are rarely applied to ex-ante research evaluation (Lividini & Fiedler 2015). The equilibrium displacement model that our study employs is commonly applied for both ex-ante and ex-post research evaluation (Alston *et al*. 2002; Moyo 2004; Moyo *et al*. 2007; Alene *et al*. 2009).

Our paper contributes to the literature on agricultural research evaluation in three ways. First, we consider an innovation that increases both supply and demand, whereas previous literature usually focused only on programmes that increase supply. Second, we focus on sorghum – an important staple food in many developing countries – while most other research evaluations focus on other crops such as maize (Alwang & Seigel 2003; Karanja *et al*. 2003; Alene *et al*. 2009), wheat (Shiferaw *et al*. 2014), peanuts (Moyo 2004; Moyo *et al*. 2007), groundnuts (Kassie *et al*. 2011) or potatoes (Godtland *et al*. 2004). Lastly, we quantify how the benefits from research differ under free trade versus trade distortions (Alston *et al*. 2002). This is an important consideration given that many developing countries impose substantial trade distortions that are harmful to the agricultural industry (Anderson 2010; Anderson *et al*. 2013).

2. Background on sorghum and Ethiopia

Ethiopia is home to 94.1 million people, 29.6% of whom live below the poverty line (World Bank 2014). Ethiopia is often seen as the centre of sorghum improvement efforts because of the great genetic diversity in the country (Fetene *et al*. 2011). Over the past 20 years, the Ethiopian government has continuously invested in the genetic improvement of sorghum, seed distribution, extension services and infrastructure improvement. Consequently, sorghum production has increased from 1.7 million tons in 2004/2005 to four million tons in 2010/2011 (Demeke & Di Marcantonio 2013). Some of this increase in production is from an expansion in growing area, but yields have also increased – from 1.4 tons/ha in 2004/2005 to two tons/ha in 2010/2011. Yet, even with this large increase in production, Ethiopia is still a net importer of sorghum because domestic consumption of sorghum is substantial (Demeke & Di Marcantonio 2013). From 2001 to 2007, sorghum comprised about 18% of cereal consumption in Ethiopia.

The average yield of sorghum (2 tons per hectare) in Ethiopia is below the global average (3.2 tons per hectare) (Taffesse *et al*. 2011). Compared to other cereals, sorghum is often considered a low-nutrient crop. Experts explain that this is primarily because people who consume sorghum are often already affected by malnutrition. This is not because sorghum has a lower nutrient content, but more so because the human digestive system is unable to digest and convert it to usable nutrients for human nutrition.

With the intention of filling this gap, USAID, the Gates Foundation, and the Australian and Ethiopian governments have been providing funding to the Ethiopian Institute of Agricultural Research (EAIR) in collaboration with US land-grant universities, and with the Queensland Alliance for Agriculture and Food Innovation, which is leading the effort to investigate ways to increase the productivity and nutritional value of sorghum. They are developing new genetically modified sorghum varieties that have high yields, high nutrient availability and are adapted to local conditions. The projects include: seed development to increase drought tolerance and resistance to biotic and abiotic stresses, and seeds that are easily digestible and tasteful. Developing drought tolerance and disease resistance increases supply and improves digestibility, while improving taste increases the demand for the crop. Starting from the initial development until the process of distribution and adoption, EAIR will be the main actor in this programme.

In Ethiopia, even though governmental market intervention has undergone major reforms in the past two decades, certain trade distortions still persist. The trade distortions that still affect the sorghum market include export bans, subsidised food imports, as well as food aid (Demeke & Di Marcantonio 2013). Anderson *et al*. (2013) argue that lowering trade distortions can play a large role in the reduction of inequality, poverty and food insecurity. Typically, the trade distortions that reduce farmers' earnings by lowering product prices discourage production and negatively affect the adoption of new technology. Following the theoretical literature by Alston *et al*. (2002), we evaluated the benefits of sorghum innovation under current trade policies and compared to benefits under the free market.

3. Model

3.1 Graphical model in the small country case

Many developing countries impose trade policies that affect farmers by lowering domestic prices below the world market price (see Anderson 2010, for example). The effects of these trade policies are illustrated in Figure 1 for a net importer, where domestic price (P_i) is lower than world price (P_w), depending on the degree of trade distortions. To simplify the graphical analysis, we assumed the case of a small country, in which changes in the domestic supply and demand have no impact on the world price. We denoted the relative distortion to price by the parameter θ, so the absolute price distortion is $P_w\theta$. Figure 1 also illustrates the research-induced change in supply and demand for the good, assuming parallel shifts in supply and demand. Technological changes shift the supply curve from S_0 to S_1 (K-shift) by increasing yields (i.e. reducing the marginal cost of production). Technological change also shifts the demand from D_0 to D_1 (δ-shift) by increasing consumers' willingness to pay for the good due to improvements in taste or nutritional value. Without trade distortions, producer surplus would have increased by area I_0CEI_1 and consumer surplus would have increased by J_0FKJ_1 due to the technological change. However, under the trade distortions, producer surplus only increases by area I_0ABI_1 and consumer surplus increases by J_0GHJ_1. The graphical analysis illustrates that producer surplus increases less as a result of the distortions (area ABCE); however, consumer surplus increases more as a result of the distortions (area FGHK). Consequently, trade distortions alter the impact of technological improvement on poverty, depending on the distribution of poverty among producers and consumers of sorghum.

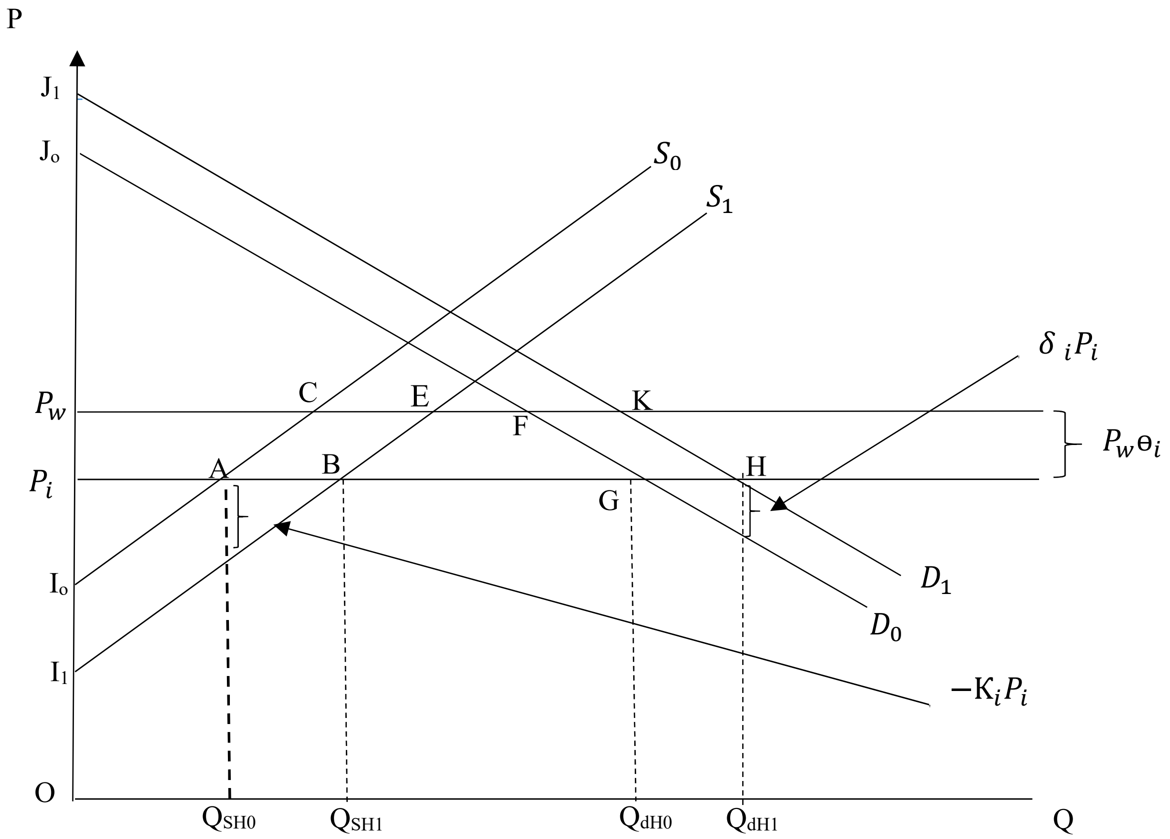

Figure 1: Research induced supply and demand shifts in the presence of a trade distortions

3.2 Equilibrium displacement model in the large country case

Next, we developed a partial equilibrium model – commonly referred to as an equilibrium displacement model – to quantify the welfare impacts of a technological innovation on sorghum in Ethiopia. We incorporated international trade in our model by assuming the case of a large country. Ethiopia accounts for 6% of global sorghum consumption (FAO 2012). The impact on world prices was expected to be small, but was included for completeness.

At equilibrium, global sorghum demand is equal to global sorghum supply. Research-induced shifts in supply and demand are measured as vertical shifts and are assumed to be parallel, as illustrated in Figure 1. The demand shifter δ measures the relative increase in willingness to pay. Similarly, Κ captures the relative reduction in marginal cost of production.

The system of equations that define the equilibrium displacement model are as follows (Alston *et al.* 2002):

$$\mathrm{dln}Q_{Si} = \varepsilon_i \mathrm{dln}P_i + \varepsilon_i \mathrm{K}_i, \ \forall i \quad (1)$$

$$\mathrm{dln}Q_{Di} = \eta_i \mathrm{dln}P_i + \eta_i \delta_i, \ \forall i \quad (2)$$

$$\sum_i^n H_{Si} \mathrm{dln}Q_{Si} = \sum_i^n H_{Di} \mathrm{dln}Q_{Si} \quad (3)$$

$$\mathrm{dln}P_i = \mathrm{dln}P_w - \theta_i, \ \forall i, \quad (4)$$

where $dlnQ_{Si}$ is the relative change in quantity supplied in country i, $dlnQ_{Di}$ is the relative change in quantity demanded, $dlnP_i$ is the relative change in the domestic price, $dlnP_w$ is the relative change in world price, ε_i is the supply elasticity, η_i is the demand elasticity, H_{Si} is country i's share of global production, H_{Di} is the share of global consumption, and there are a total of n countries. We denote all of the relative changes in variables as $dlnX$, where $dlnX = dX/X$.

The system was solved by inserting Equation (4) into Equations (1) and (2). Substituting these two equations into Equation (3) and solving for $dlnP_w$ gives

$$\mathrm{dln}P_w = \frac{\sum_i^n [H_{Di}\,\eta_i(\delta_i - \theta_i) - H_{Si}\varepsilon_i\,(\mathrm{K}_i - \theta_i)\,]}{\sum_i^n [H_{Si}\,\varepsilon_i - H_{Di}\eta_i]}. \tag{5}$$

We considered the case of two countries, Ethiopia and the rest of the world. We only considered the effect of trade distortions and technological innovation in Ethiopia, so we set $\theta = 0$, $\delta = 0$, and $\mathrm{K} = 0$ for the rest of the world.

Assuming that linear supply and demand approximate the true supply and demand near equilibrium, we calculated changes in aggregate measures of economic surplus due to the research-induced shifts in supply and demand (Alston *et al*. 2002) as:

$$\Delta\mathrm{PS}_i = P_i{}^o Q_{Si}{}^o(\mathrm{dln}P_i + \mathrm{K}_i)(1 + 0.5\mathrm{dln}Q_{Si}), \tag{6}$$

$$\Delta\mathrm{CS}_i = -P_i{}^o Q_{Di}{}^o(\mathrm{dln}P_i + \delta_i)(1 + 0.5\mathrm{dln}Q_{Di}), \tag{7}$$

$$\Delta\mathrm{TS}_i = \Delta\mathrm{PS}_i + \Delta\mathrm{CS}_i, \tag{8}$$

where ΔPS represents the change in producer surplus, ΔCS represents the change in consumer surplus, and ΔTS represents the change in total surplus. Baseline prices and quantity before the technological innovation are denoted with a 0 superscript.

3.3 Calculating research-induced shifts in supply and demand

We calculated the relative reduction in per ton cost of production (K_e) using the following formula (Alston *et al*. 2002:380):

$$\mathrm{K}_i = \left[\frac{dlnG_i}{\varepsilon_i} - \frac{dlnC_i}{1+dlnG_i}\right] prob(G)_i A_i\,(1 - \sigma_i), \tag{9}$$

where $dlnG$ represents the proportionate change in yield per hectare for those farmers who adopt the new sorghum variety, $dlnC$ represents the proportionate change in variable cost per hectare for those farmers who adopt the new sorghum variety, ε_i represents the supply elasticity, $Prob(G)$ represents the probability of achieving the increase in yield, A represents adoption rate, and σ represents the depreciation rate of the technology.

While Alston *et al*. (2002) only consider a shift in supply, we extended the logic of the equation above to the case of a shift in demand. We calculated the proportionate change in willingness to pay per ton of sorghum (δ) using the formula

$$\delta_i = dlnW_i \cdot prob(W)_i \cdot B_i, \tag{10}$$

where $dlnW$ represents the proportionate change in willingness to pay per ton of product for those people who consume the new sorghum variety, $Prob(W)$ represents the probability of increasing the willingness to pay by $dlnW$, and B represents the proportion of total sorghum consumption by the new sorghum varieties.

3.4 Modelling changes in incomes

For this study, predicted income changes of households was predicted by allocating the aggregate economic surplus to households that would most likely benefit from the innovation. We used data on households that previously adopted improved sorghum varieties to predict those households that were most likely to adopt the new variety, following a procedure similar to Moyo *et al*. (2007). We estimated the probability of adoption using a probit model and then selected those with the highest probability as adopters. Using a probit model is necessary because the assumed level of adoption of the new variety may not necessarily equal the proportion of adopters of past varieties, so we needed to estimate which households had the highest probability of adoption.

Based on the households' share of sorghum production, we distributed producer surplus to those households that were most likely to adopt. Moyo *et al*. (2007) did not model the distribution of consumer surplus among households since the technological innovation, as they only considered the affected supply. Our approach used two types of consumer surplus. One was the consumer gain from an increase in willingness to pay ($\Delta \mathrm{CS}^{\delta}{}_{i}$), and the other was consumer gain from general price reduction ($\Delta \mathrm{CS}^{\mathrm{dln}P_i}$) due to increase in supply of sorghum. We assumed that consumer surplus from the increase in willingness to pay was distributed only among those who adopted the new variety for production. Our implicit assumption was that the sorghum market does not segregate the new variety, because the cost of segregating the market is prohibitive. Therefore, only households that produced the new sorghum variety enjoyed the increased willingness to pay for consumption attributes. Consumer gain from the price reduction was distributed to all sorghum consumers, depending on previous consumption share. A household's change in welfare associated with the improved sorghum variety was estimated as:

$$\Delta \mathrm{Y}_{ji} = U_{ji} * \Delta \mathrm{PS}_i + \; + Z_{ji} \Delta \mathrm{CS}^{\delta}{}_{i} + V_{ji} * \Delta \mathrm{CS}^{\mathrm{dln}P_i}{}_{i}, \tag{11}$$

where ΔY_{ji} represents the welfare change of household j, U_{ji} represents the production share, Z_{ji} represents consumption share due to increase in willingness to pay, and V_{ji} represents the consumption share due to decrease in price.

The post-research level of real income (Y_j^*) for households is

$$\mathrm{Y}_{ji}{}^{*} = \mathrm{Y}_{ji}{}^{0} + \Delta \mathrm{Y}_{ji}\,, \tag{12}$$

where $\mathrm{Y}_j{}^0$ represents the pre-research household-specific income level.

3.5 Modelling changes in poverty

We calculated the projected change in poverty by comparing the new income level per capita from equation (12) to the poverty line. Poverty indices (T) were also calculated using the commonly known method of Foster *et al*. (1984), which is defined as:

$$T_{\alpha i} = \frac{1}{N} \sum_{j=0}^{q} \left[\frac{Z_i - \mathrm{Y}_{ji}{}^{*}}{Z_i} \right]^{\alpha}, \tag{13}$$

where $T_{\alpha i}$ is the poverty index for country I, α is a parameter of inequality aversion, N is the total number of households, q is the number of poor households, $\mathrm{Y}_j{}^*$ is the income or expenditure of the j$^{\text{th}}$

poor household, and Z is the poverty line with the same unit as Y. The value of α is set at 0, 1 and 2. At α equal to 0, 1 and 2 the index becomes a measure of poverty rate, poverty gap and poverty severity respectively (Foster *et al.* 1984).

3.6 Parameter values and data

The sorghum innovation programme that we evaluated started in 2014 but is not expected to distribute new sorghum varieties until 2022. Since the technology development is at an early stage, experts are unable to predict precisely the values that determine the K and δ shifters, which are fundamental in finding the economic contribution. As a result, we have developed scenarios of K and δ shifters (listed in Table 1) that cover the values considered plausible by experts involved in the programme. Currently, nearly 15% of the sorghum farmers are using improved sorghum varieties. Therefore, this rate is considered as one potential average adoption rate (Table 1) for the new sorghum technology; however, we also include 10% and 20% adoption rate scenarios. In all scenarios, the probability of success for both increased yield per hectare and increase in willingness to pay per ton per household is assumed to be 0.5. Depreciation cost of the new seed is assumed to be zero.

Table 1 presents the resulting K and δ shifters. K and δ are lowest in scenario 1 and highest in scenario 6. We assumed that the only consumers who experience the consumption benefits of the new sorghum variety are those that produce the variety. The consumption adoption rate (B_e) is found by multiplying the proportion of sorghum consumers who produce sorghum (86%) with the production adoption rate assumed in each scenario.

Table 1: Determining K_e and δ_e shifters

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
$\mathrm{dln}G_e$	0.750	0.750	0.750	0.750	0.750	0.750
$\mathrm{dln}C_e$	0.250	0.400	0.400	0.400	0.400	0.400
A_e	0.100	0.150	0.150	0.150	0.200	0.200
$\mathrm{dln}W_e$	0.400	0.000	0.300	0.450	0.250	0.350
B_e	0.086	0.130	0.130	0.130	0.170	0.170
K_e	0.030	0.040	0.040	0.040	0.050	0.050
δ_e	0.020	0.000	0.020	0.030	0.020	0.030

Table 2 reports the parameters used in our equilibrium displacement model. The price elasticity of sorghum demand of -0.66 was obtained from the study by Tafere *et al.* (2010). The demand elasticity of sorghum for rest of the world was assumed to be -0.85, averaging demand elasticities of sorghum producers collected from the FAO (2012) report. Similarly, the price elasticity of sorghum supply of 1.0 was used based on the studies by Suleiman (2003) and Alston *et al.* (2002), which suggest that a supply elasticity of 1.0 is a good starting point.

Pre-research sorghum price and quantity under trade distortions were obtained by averaging FAOSTAT data from 2009, 2010, 2011 and 2012. Additionally, the pre-research sorghum quantity demanded under trade distortions was taken from Tafere *et al.* (2010). Based on Demeke and Di Marcantonio (2013), we assumed an average sorghum trade distortion of 20% (adjusted nominal rate of protection) for Ethiopia.

Under free trade, although it is unobservable, pre-research sorghum price and quantities (supply and demand) were estimated hypothetically. The free trade price ($190) was calculated by dividing the price under trade distortion ($152) by one minus the trade distortions (1-0.20). Next, using elasticities (1.00 elasticity of supply and -0.66 elasticity of demand), pre-research quantities (3 680 000, quantities of supply and 3 987 000, quantities of demand), and prices ($152, $190), we were then able to find supply and demand quantities of 4 600 000 and 2 990 250 tons per year correspondingly.

Table 2: Parameters and values

Parameters	Values
Own price elasticities of sorghum demand for Ethiopia	-0.66
Own price elasticity of sorghum demand for rest of the world	-0.85
Own price elasticities of sorghum supply for Ethiopia	1.00
Own price elasticities of sorghum supply for rest of the world	1.00
Pre-research sorghum price per ton under trade distortions in Ethiopia	152 USD
Pre-research tons of sorghum quantity supplied per year under trade distortions in Ethiopia	3 680 000
Pre-research tons of sorghum quantity demanded per year under trade distortions in Ethiopia	3 897 000
Trade distortions in Ethiopia	0.20
Pre-research sorghum price per ton under free trade in Ethiopia	190 USD
Pre-research tons of sorghum quantity supplied per year under free trade in Ethiopia	4 600 000
Pre-research tons sorghum quantity demanded per year under free trade in Ethiopia	2 990 250

We utilised the World Bank Ethiopian household-level survey data collected in 2011/2012 to estimate the probabilities of adoption and impacts on poverty. This is nationally representative data that includes 3 969 sample farm households. Out of these sample farm households, 1 420 are reported incomplete and 2 166 completed the full survey. Table 3 presents descriptive statistics of key variables. The average age of the sample households was 44 years old. We estimated the sample household's income using the expenditure approach (Meyer & Sullivan 2003). The average income per household was 3 320 US dollars per year. Sample households' land ownership was 1.729 hectares per household. Fifty percent of the sample households were from the Oromia and Amhara regions, where sorghum is the main crop.

Table 3: Descriptive statistics of key variables[a]

Independent variables		Households (N = 2166)	
		Mean	Standard error
Age	Age of household head in years	44.410	15.471
Household income	Household income in $ per year	3 320	1 723.273
Farm size	Total farm area measured in hectares	1.729	1.711
Extension service	Extension services: 1 if farmer gets extension services and 0 otherwise	0.320	0.415
Education	Education: 1 if farmer can read and write and 0 otherwise	0.390	0.486
Household head	Household head: 1 if female household head and 0 otherwise	0.190	0.393
Credit access	Credit access: 1 if farmer has access to credit and 0 otherwise	0.260	0.428
Crop rotation	Crop rotation: 1 if farmer rotates crops and 0 otherwise	0.790	0.426
Large ruminant ownership	Large owned livestock: number of livestock measured in heads	4.440	4.517
Fertiliser	Fertiliser application: 1 if farmer uses fertiliser and 0 otherwise	0.750	0.415
Land rent	Land rent: 1 if farmer rents land and 0 otherwise	0.500	1.095
Family size	Number of family members	5.260	0.487
Region	Location: 1 if farmer lives in Oromia or Amhara and 0 otherwise	0.500	0.500
Sorghum producers	Percentage of households that produce sorghum	0.36	0.48

[a] Source: World Bank Ethiopian household-level survey data 2011/2012

4. Result and discussion

4.1 Economic surplus

Table 4 presents the price and quantity impacts of the technological improvement in Ethiopia under the six scenarios calculated using equations (1) to (5). The change in prices and quantities under the free trade model versus trade distortions are nearly equivalent, so we only report changes in prices and quantity with current trade distortions. The results in Table 4 suggest that the shifts in supply and demand in Ethiopia have very small impacts on prices, given that Ethiopia is a small portion of the global sorghum market. For example, in scenario 1, the Ethiopian and world price drops by around 0.14%. Note that the magnitude of global and domestic price changes increase with increase in Ҡ (supply) and δ (demand) shifters. World and Ethiopian sorghum prices decreased by 0.14, 0.13, 0.18, 0.20, 0.21 and 0.23% in scenarios 1, 2, 3, 4, 5 and 6 respectively.

Table 4: Effects of sorghum development programme in prices and quantities

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
$\text{dln}P_w$	-0.0014	-0.0013	-0.0018	-0.0020	-0.0021	-0.0023
$\text{dln}P_i$	-0.0014	-0.0013	-0.0018	-0.0020	-0.0021	-0.0023
$\text{dln}Q_{Si}$	0.0286	0.0387	0.0382	0.0380	0.0479	0.0477
$\text{dln}Q_{Di}$	0.0142	0.0009	0.0144	0.0211	0.0146	0.0213

The relative change in quantity supplied and demanded is shown in the last two rows of Table 4. Quantities of supply and demand increased by 2.86 and 1.42% in scenario 1; 3.87 and 0.09% in scenario 2; 3.82 and 1.44% in scenario 3; 3.80 and 2.11% in scenario 4; 4.79 and 1.46% in scenario 5; and 4.77 and 2.13% in scenario 6.

Table 5 shows the estimates of aggregate annual welfare impacts. Consistent with our graphical analysis in Figure 1, the technological innovation increased producer surplus more under free trade and increased consumer surplus more under trade distortions. For example, in scenario 6, producer surplus increased by $42 664 089 per year under free trade as compared to increasing by $22 267 892 under trade distortions. On the other hand, the increase in consumer surplus per annum was higher under trade distortions ($28 709 699) than under free trade ($18 559 452). Whether technological innovation increases total surplus more under free trade or trade distortions depends on the magnitude of the changes in producer and consumer surplus. In all the scenarios we found that total surplus increased more under free trade. Our results match with those of Anderson (2010) and Anderson *et al*. (2013), who argue that policies of developing countries reduce the size of research benefit and alter the distribution of those benefits. However, even under trade distortions, the benefits from the sorghum innovation were large. The total benefit gained from the programme under trade distortions was $34 531 966 in scenario 1, $25 818 197 in scenario 2, $39 321 918 in scenario 3, $46 135 192 in scenario 4, $44 164 256 in scenario 5, and $50 977 591 in scenario 6.

Table 5: Welfare effects of sorghum development programme in Ethiopia, in US dollar

		1	2	(2-1)
Scenario	Parameters	Under trade distortion model	Under free trade model	Difference
1	ΔPS_i	13 186 560	25 318 716	12 132 156
	ΔCS_i	21 345 406	12 266 736	-9 078 670
	ΔTS_i	34 531 966	37 585 452	3 053 486
2	ΔPS_i	17 974 713	34 472 952	16 498 238
	ΔCS_i	7 843 483	742 253	-7 101 231
	ΔTS_i	25 818 197	35 215 205	9 397 007
3	ΔPS_i	17 756 266	34 055 747	9 488 613
	ΔCS_i	21 565 652	12 454 864	-9 110 788
	ΔTS_i	39 321 918	46 510 611	7 188 693
4	ΔPS_i	17 647 086	33 847 214	16 200 128
	ΔCS_i	28 488 105	18 370 032	-10 118 074
	ΔTS_i	46 135 192	52 217 246	6 082 054
5	ΔPS_i	22 378 315	42 874 565	20 496 250
	ΔCS_i	21 785 940	12 643 032	-9 142 909
	ΔTS_i	44 164 256	55 517 597	11 353 341
6	ΔPS_i	22 267 892	42 664 089	20 396 196
	ΔCS_i	28 709 699	18 559 452	-10 150 247
	ΔTS_i	50 977 591	61 223 540	10 245 949

4.2 Net present value and modified internal rate of return

Information collected from the administrative and research specialists of the EAIR programme indicated that the research costs were estimated to be 32 408 491.87 US dollars for a 10-year research period (2014 to 2023). We assumed additional miscellaneous expenses of 20%. In total, this gave a total cost of the programme estimated to be 38 890 190.25 US dollars. We assumed that the costs covered were incurred prior to the adoption process.

We simulated the net present value of the research over a 15-year period of adoption under trade distortions and free trade for each scenario, assuming a 5% discount rate. The modified internal rate of return (MIRR) over 15 years at a 5% finance rate and 10% re-investment rate was also estimated. MIRR is a similar concept to the internal rate of return (IRR), but MIRR uses different finance and re-investment interest rates that provide a more plausible estimate of the rate of return (Hurley *et al.* 2014). As farmers' adoption tends to be lower in the beginning few years, we assumed an adoption rate of 1% in year 2022, 3% in year 2023, and 7% in year 2024, before it would reach the maximum in year 2025. For simplicity, we assumed the same adoption rate for the first three years in all the scenarios. In other words, the different adoption rates in Table 2 refer to different adoption rates from the fourth year (2025, maximum adoption). Once we had determined the associated values of the K and δ shifters for each year, we calculated the total surplus (economic contribution) of the programme in each year using equations (6), (7) and (8). Then we calculate the net present values over 15 years for each scenario.

Our estimates of the net present value for each scenario are given in Table 6. The net present value of the programme was higher under free trade than under trade distortions, consistent with our results in Table 5. For example, in scenario 6 (with the highest net present value (NPV) across all scenarios), the net present value under free trade ($358 232 038) is higher when compared to the net present value under trade distortions ($286 827 151). This means that there will be US$71 404 886 greater gains under free trade than under trade distortions. The net present values under both trade distortions and free trade are $192 638 161 and $201 554 185 in scenario 1, $154 328 724 and $192 267 312 in scenario 2, $218 701 574 and $250 118 369 in scenario 3, $255 774 418 and $281 169 692 in scenario 4, and $245 050 030 and $299 127 785 in scenario 5 respectively. The modified internal rates of return obtained among the different scenarios are not that much different from one to another. The MIRRs of the programme were between 19% and 23% across all scenarios considered. These rates of return are broadly in line with the MIRR estimates in the study by Hurley *et al.* (2014).

Table 6: Net present value (NPV) and modified internal rate of return (MIRR) of the sorghum development programme in Ethiopia in US dollar

Scenario	NPV_i and $MIRR_i$	1	2	(2-1)
		Under trade distortion model	Under free trade model	Difference
1	NPV_i	$192 638 160.86	$201 554 184.63	$8 916 023.77
	$MIRR_i$	20%	20%	0%
2	NPV_i	$154 328 723.78	$192 267 312.34	$37 938 588.56
	$MIRR_i$	19%	20%	1%
3	NPV_i	$218 701 573.71	$250 118 368.48	$31 416 794.77
	$MIRR_i$	20%	21%	1%
4	NPV_i	$255 774 418.30	$281 169 691.97	$25 395 273.67
	$MIRR_i$	21%	22%	1%
5	NPV_i	$245 050 029.52	$299 127 785.09	$54 077 755.57
	$MIRR_i$	21%	22%	1%
6	NPV_i	$286 827 151.17	$358 232 037.47	$71 404 886.30
	$MIRR_i$	22%	23%	1%

4.3 Adoption of new sorghum variety

The economic surplus measures aggregate benefits, and there are about 1 000 000 sorghum farmers that have a potential to benefit from the programme. Next, we identified likely beneficiaries and distributed research gains to the individuals. Research beneficiaries depend explicitly on household characteristics. In the World Bank Ethiopian household-level survey data of 2011/2012, households were asked if they used improved or traditional sorghum seed. We estimated the probability of adopting the new sorghum using a binary probit model. Factors that were statistically significant in affecting the decision to adopt the new improved sorghum variety included location, extension service, crop rotation and fertiliser (see Table 7). Following Moyo *et al*. (2007), we allocated producer surplus among the producers with the highest probability of adoption estimated from the probit model. Among the households that were predicted to adopt the new variety, we allocated the producer surplus based on their previous production shares. Similarly, we allocated consumer surplus among those that adopted the new variety for production according to their previous consumption shares.

Table 7: Factors that affect new sorghum variety adoption

	Probit model for adoption decision					
	Parameters			Marginal effects		
Variables	Estimates	Std. error	P-value	Estimates	Std. error	P-value
Intercept	-2.9105	0.3337	0.0000	-	-	-
Location	-0.2033	0.1066	0.0560	-0.0174	0.0092	0.0580
Age	-0.0033	0.0038	0.3760	-0.0003	0.0003	0.3770
Household income	-0.0004	0.0003	0.280	-0.0002	0.0026	0.2810
Farm size	0.0284	0.0307	0.3550	0.0024	0.0026	0.3550
Extension service	0.5337	0.1103	0.0000	0.0455	0.0098	0.0000
Education	0.0636	0.1092	0.5610	0.0054	0.0093	0.5610
Household head	-0.1333	0.1579	0.3980	-0.0114	0.0135	0.3990
Credit access	0.0291	0.1126	0.7960	0.0024	0.0096	0.7960
Family Size	0.0252	0.0256	0.3240	0.0022	0.0021	0.3250
Crop rotation	0.6786	0.2351	0.0040	0.0579	0.0204	0.0050
Large ruminant ownership	0.0112	0.0300	0.3890	0.0010	0.0011	0.3890
Fertilizer	0.4383	0.2034	0.0310	0.0374	0.0175	0.0330
Land rent	-0.0282	0.0447	0.5280	-0.0024	0.0038	0.5280
	Log likelihood function = -352.5176					
	Pseudo R^2 = 0.2016					
	Number of observations = 2166					

4.4 Income and poverty changes

The associated income and poverty changes are presented in Table 8. As we discussed above, the benefit of the programme is larger under free trade, with greater benefits to producers; however, the predicted income and poverty changes are nearly identical under free trade or trade distortions, since the overall impacts on poverty are relatively small. Therefore, we only show the results under trade distortions, since it is the current policy. Average household income increased from \$3 320, to \$3 323 to \$3 326, depending on the scenario. The small impact on household income is due to few beneficiaries (sorghum farmers who adopt the new variety) and because sorghum accounts for only 30% of the income of sorghum producers. Among sorghum producers, the average household income increased from \$3 120, to \$3 147 to \$3 293, depending on the scenario. The average income of sorghum producers is lower than the average household income, which is consistent with Karanja *et al*. (2003), who state that sorghum is the crop of the poor.

The average rate of poverty before the programme was 30.19%. The poverty rate decreased marginally only in scenarios 5 and 6. The average poverty gap before the programme was 25.31%. Again, the reduction in the poverty gap was small across all scenarios. The poverty severity before the programme was 9.36% and decreased only slightly as a result of the programme. The change in poverty indices stated above indicate minimal impacts of this particular sorghum innovation programme on aggregate poverty reduction. Of course, the particular programme we consider is only one effort within the region to achieve agricultural development.

Our results of the impact on poverty are similar to those in previous research. For comparison purposes, in scenario 2 we assumed only a change in supply, similar to Moyo *et al*. (2007), who studied the impact of peanut research on poverty in Uganda with the same adoption rate assumption (15%). We found a similar impact of research in Ethiopia on the poverty gap and poverty severity. In scenario 2, where we assumed change in the supply only, the poverty gap and severity were reduced by 2% and 5% respectively with a 15% adoption rate. Likewise, these indices were reduced by 0.06 and 0.03 under the assumption of an open economy and 0.07 and 0.05 under the assumption of a closed economy in Moyo *et al*. (2007).

Table 8: Change in income and poverty indices due to sorghum development[a]

Income and poverty indices under trade distortions	Before the programme	After the programme					
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Mean household income ($)	3 320	3 324	3 323	3 324	3 324	3 325	3 326
Poverty rate	0.3019	0.3019	0.3019	0.3019	0.3019	0.2991	0.2987
Poverty gap	0.2531	0.2523	0.2524	0.2520	0.2519	0.2500	0.2502
Poverty severity	0.0936	0.0930	0.0931	0.0929	0.0928	0.0918	0.0919

[a] 1 US dollar = 15 Ethiopian Birr (average exchange rate for years 2010, 2011 and 2012)

5. Conclusion

This paper has examined the economic contribution of sorghum research and development in Ethiopia. We used an equilibrium displacement model that accounted for market impacts in the presence of trade distortions. We assessed the impact on individual households and poverty by allocating the aggregate welfare impacts using estimates of the probability of adopting the new sorghum variety from household data on the basis of the adoption of previous improved varieties.

The innovation that we considered results in benefits both to the producers and consumers. Producers benefit more from innovations under free trade relative to current trade distortions, while consumers benefit less under free trade. The total benefits gained from the programme under trade distortions is between $26 million and $51 million per year, depending on the scenario. However, the benefits from the programme could be $3 million to $10 million larger per year if trade distortions were eliminated. The results illustrate the important interaction between agricultural distortions and the benefits from agricultural research.

The average annual household income in the presence of trade distortions increased by about $3 to $6, depending on the scenario considered. This small change in income results in a small change in the poverty indices. The small impact on poverty indices is not surprising, given that there are relatively few expected beneficiaries – only sorghum farmers who adopt the new variety (7.5% of the total sample size), and sorghum accounts for only 30% of the income of sorghum producers.

References

Ahmed MM, Sanders JH & Nell WT, 2000. New sorghum and millet cultivar introduction in Sub-Saharan Africa: Impacts and research agenda. Agricultural Systems 64(1): 55–65.

Alene AD & Coulibaly O, 2009. The impact of agricultural research on productivity and poverty in sub-Saharan Africa. Food Policy 34(2): 198–209.

Alene AD, Menkir A, Ajala SO, Badu□Apraku B, Olanrewaju AS, Manyong VM & Ndiaye A, 2009. The economic and poverty impacts of maize research in West and Central Africa. Agricultural Economics 40(5): 535–50.

Alston JM, Edwards GW & Freebairn JW, 1988. Market distortions and benefits from research. American Journal of Agricultural Economics 70(2): 281–8.

Alston JM, Norton GW & Pardey PG, 2002. Science under scarcity: Principles and practice for agricultural research evaluation and priority setting. Ithaca NY: Cornell University Press.

Alwang J & Siegel PB, 2003. Measuring the impacts of agricultural research on poverty reduction. Agricultural Economics 29(1): 1–14.

Anderson K, 2010. Krueger, Schiff, and Valdés revisited: Agricultural price and trade policy reform in developing countries since 1960. Applied Economic Perspectives and Policy 32(2): 195–231.

Anderson K, Rausser G & Swinnen J, 2013. Political economy of public policies: Insights from distortions to agricultural and food markets. Journal of Economic Literature 51(2): 423–77.

Becerril J & Abdulai A, 2010. The impact of improved maize varieties on poverty in Mexico: A propensity score-matching approach. World Development 38(7): 1024–35.

Byerlee D & Sain G, 1986. Food pricing policy in developing countries: Bias against agriculture or for urban consumers? American Journal of Agricultural Economics 68(4): 961–9.

Clover J, 2003. Food security in sub-Saharan Africa. African Security Studies 12(1): 5–15.

Demeke M & Di Marcantonio F, 2013. Analysis of incentives and disincentives for sorghum in Ethiopia. Technical notes series, MAFAP, FAO, Rome.

FAO, 2012. Available at http://faostat.fao.org/site/339/default.aspx (Accessed 20 June 2015).

Fetene M, Okori P, Gudu S, Mneney EE & Tesfaye K, 2011. Delivering new sorghum and finger millet innovations for food security and improving livelihoods in Eastern Africa. Available at https://cgspace.cgiar.org/handle/10568/10811 (Accessed 3 July 2014).

Foster JE, Greer J & Thorbecke E, 1984. A class of decomposable poverty measures. Econometrica 52(3): 761–6.

Godtland EM, Sadoulet E, De Janvry A, Murgai R & Ortiz O, 2004. The impact of farmer field schools on knowledge and productivity: A study of potato farmers in the Peruvian Andes. Economic Development and Cultural Change, 53(1): 63–92.

Hurley TM, Rao X & Pardey PG, 2014. Re-examining the reported rates of return to food and agricultural research and development. American Journal of Agricultural Economics 96(5): 1492–1504.

Karanja DD, Renkow M & Crawford EW, 2003. Welfare effects of maize technologies in marginal and high potential regions of Kenya. Agricultural Economics 29(3): 331–41.

Kassie M, Shiferaw B & Muricho G, 2011. Agricultural technology, crop income, and poverty alleviation in Uganda. World Development 39(10): 1784–95.

Lividini K & Fiedler JL, 2015. Assessing the promise of biofortification: A case study of high provitamin A maize in Zambia. Food Policy 54: 65–77.

Meyer BD & Sullivan JX, 2003. Measuring the well-being of the poor using income and consumption. National Bureau of Economic Research working paper No. 9760, NBER, Cambridge MA.

Moyo S, 2004. The economic impact of peanut research on the poor: The case of resistance strategies to control peanut viruses in Uganda. Doctoral dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA.

Moyo S, Norton GW, Alwang J, Rhinehart I & Deom CM, 2007. Peanut research and poverty reduction: Impacts of variety improvement to control peanut viruses in Uganda. American Journal of Agricultural Economics 89(2): 448–60.

Shiferaw B, Kassie M, Jaleta M & Yirga C, 2014. Adoption of improved wheat varieties and impacts on household food security in Ethiopia. Food Policy 44: 272–84.

Suleiman A, 2003. Estimating supply response in the presence of technical inefficiency using the profit function: An application to Ethiopian agriculture (No. 03/4). Department of Economics, University of Leicester, Leicester UK.

Tafere K, Taffesse AS, Tamiru S, Tefera N & Paulos Z, 2010. Food demand elasticities in Ethiopia: Estimates using household income consumption expenditure (HICE) survey data. Ethiopia Strategy Support Program II, Working paper 11, IFPRI, Addis Ababa, Ethiopia.
Taffesse AS, Dorosh P & Asrat S, 2011. Crop production in Ethiopia: Regional patterns and trends. Washington DC: International Food Policy Research Institute.
Taylor JRN, 2003. Overview: Importance of sorghum in Africa. Workshop held at the Afripro Conference, Workshop on the proteins of sorghum and millets: Enhancing nutritional and functional properties for Africa, 2–3 April, Pretoria, South Africa.
World Bank, 2014. Available at http://www.worldbank.org/en/country/ethiopia (Accessed 10 May 2015).