Ex-Ante Analysis of the Benefits of Transgenic Drought Tolerance Research on Cereal Crops in Low-Income Countries

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Abstract

This paper examines the ex-ante benefits of transgenic research on drought in eight developing countries, including the potential magnitude of private sector profits. The framework employs country-specific agroecological-drought risk zones and considers both yield increases and yield variance reductions when estimating producer and consumer benefits from research. Risk benefits from yield variance reductions are shown to be an important component of aggregate drought research benefits, representing 41 percent of total benefits across the eight countries. Further, estimated annual benefits of $US 93 million to the private sector suggest that significant incentives exist for private sector participation in varietal drought tolerance research.

Drought has been recognized as one of the most costly threats to agriculture. Its consequences are most severe in developing countries. For example average annual production losses in tropical areas due to drought are estimated at 25 million metric tons of rice and 20 million metric tons of maize, equivalent to around $US 7 billion per year (Doering, 2005). Similarly, maize losses in non-temperate areas were estimated to be about 19 million metric tons during the early 1990s or approximately $US 1.9 billion (Edmeades, Bolaños and Lafitte, 1992). Further, given that 65 percent of poor rural households reside in drought prone areas, technologies that alleviate drought have the potential to significantly benefit the world's poor.

This paper documents the ex-ante impact of transgenic research to mitigate drought in maize, rice, and wheat rain-fed areas of India, Indonesia, Bangladesh, The Philippines, Kenya, Ethiopia, Nigeria, and South Africa. While past research has focused almost exclusively on benefits generated by expected mean yield increases, the present study estimates the important benefits of yield variance reductions as measured by risk reduction to producers and consumers through changes in the variances of incomes and prices, respectively. For example, Traxler et al. (1995) find that the post Green Revolution in wheat is characterized by a relatively rapid improvement in yield stability and slow yield growth. The incentives potential seed markups create for private sector involvement in transgenic research on drought tolerance in major crops are also explored in the ex-ante simulations.

The rest of the paper is organized as follows. Section two provides a discussion on biotechnology and public-private partnerships to develop drought resistant varieties. A spatial framework used to construct agroecological-drought risk zones for rain-fed production of maize, rice, and wheat is discussed in section three. Section four lays out the model used to calculate the benefits of new yield enhancing and variability reducing drought tolerant varieties. A description of the economic data and technological parameters is provided in section five and results are discussed in section six. Section seven concludes.

Biotechnology and public-private partnerships to develop transgenic drought tolerant varieties

Advances in molecular biology and genetic engineering have the potential to reduce drought related losses in many crops and cropping systems (CGIAR, 2003; FAO, 2003; Doering, 2005). A number of genetically engineered varieties have been successfully generated and disseminated, with the planted global area rapidly expanding from 4.2 million acres in 1996 to 222 million acres in 2005. However, genetic engineering requires considerable financial resources and highly specialized skills, which presently tends to restrict its application and commercialization to the domain of multinational biotechnology companies. Furthermore, the private sector often has limited incentives to invest in drought related biotechnology research for developing countries, given constraints on market size, market infrastructure, and property rights protection that limit potential returns on investments (Hareau, Mills, and Norton, 2006). Consequently there has been limited application of genetic engineering to generate drought resistance varieties for important food crops like maize, rice and wheat. On the other hand, results from the experiments that do exist are promising. For example, insertions of drought tolerant genes into maize have generated 10-23 percent higher yields under drought stress compared to traditional maize varieties (Garg et al., 2002). Similar work has also been applied to wheat, with 30 percent increases in fresh weight (e.g. Abebe et. al., 2003) and rice (e.g. Quan et al., 2004) with 15 percent increases in photosynthesis efficiency.

Public-private partnerships are potentially an important mechanism for the successful generation and delivery of drought tolerant crops to food-insecure farmers (Tripp, 2002; Falcon and Fowler, 2002; Pingali and Traxler, 2002; Doering, 2005). Low-income countries, alone, have limited human and physical capital to invest in modern drought-related research. On the other hand, the private sector has significant resources but limited incentives to invest in the generation of drought resistant technologies.[1] International agricultural research centers, such as those of the CGIAR, are also likely to play an important role in collaborative arrangements by both augmenting national system research capacities and reducing private sector costs. However, the feasibility of public-private collaborative arrangements depends critically on a clear understanding on the magnitude of potential benefits for distribution among partners.

Spatial framework for evaluation

Significant geographic variation in rainfall and other factors influencing drought implies the need for a spatially explicit evaluation framework. The current framework starts with a total of sixteen agroecological zones (FAO/IIASA, 2000) and three drought risk types (low, medium, and high).[2] In order to delineate the agroecological-drought risk zones in each country, drought risk maps are overlaid with agroecological zone maps and combined with maps of rain-fed cropped areas. Two key simplifications are then made to reduce the number of zones but still

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[1] The top ten leading multinational biotech companies' annual expenditures in agricultural research and development is $US 3 billion. Plant improvement research and development expenditures of the CGIAR which is the largest international public sector institution are roughly $US 300 million. Similar expenditures in the national agricultural research systems of China, India, and Brazil are less than $500,000 (Pingali and Traxler, 2002).

[2] Georeferenced drought risk and agroecological zone data were obtained from the International Food Policy Research Institute (IFPRI), using a consistent global grid with a 10km x 10km pixel resolution. IFPRI also provided compatible sets of georeferenced annual crop production and harvested area data (annual averages for the period 2002-2004). Drought risk is derived by taking 30 years of historic rainfall and evapotranspiration data for each pixel as input in a soil moisture model that accounts for both the depth and water holding properties of local soils (Fischer et al., 2002).

preserve a satisfactory level of detail for the evaluation of drought risk. First, given that only a small percentage of areas fall under low drought risk, low drought risk zones are joined with medium drought risk zones and reported as low-med drought risk. Second, agroecological zones in humid and sub-humid areas are combined and reported as humid/sub-humid. These zones provide relatively uniform environments within which the assessment of alternative research strategies can be undertaken.

Crop production and harvested areas are then estimated for the resulting agroecological-drought risk zones within each country. Results for India are provided in Panel 1 as an example.[3] Estimated production and harvested area data for the agroecological-drought risk zones within each country are then reported in table 1. These estimates show that rice is the most important crop for the rain-fed agricultural areas in India, Indonesia, Bangladesh and Philippines, whereas maize is the most important crop for the rain-fed agricultural areas of the four African countries. In general, rain-fed production is distributed over multiple zones in each country, but for most countries the production of crops is concentrated within one agroecological-drought risk zone. For example, in Ethiopia more than 90 percent of the maize production is concentrated in the humid/sub-humid low-medium drought risk zone which occupies most of the rain-fed area. Cross-country comparisons also indicate many common agroecological-drought risk zones. For example, India and Indonesia have three common agroecological-drought risk zones that encompass almost all of their maize and rice production.

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[3] Due to space limitations, the agroecological-drought risk zones and crop production for the other seven countries are not illustrated here and are available upon request.

The model

Benefits of mean yield increases

A framework to evaluate the potential impact of technologies that increase mean yields through consumer and producer surplus changes at the market level is well developed (see Alston, Norton and Pardey, 1995). In order to maintain consistency with benefit measures of research induced variance reductions, a slightly simplified approach is applied in this study whereby benefits of mean yield increases are measured as changes in producer and consumer income for each agroecological-drought risk zone.[4] Under this set up, each zone is assumed to consist of a representative producer and a representative consumer. Drought resistant research generates yield increases which can also be expressed as a unit cost reduction in the producer's marginal cost. The producer then experiences a change in income from lower production costs and potentially, also a lower price from market induced price changes. The consumer experiences a gain in well-being from a market induced reduction in price.

The changes in producer income and consumer well-being can therefore be approximated as:

$$Pr.\ Y = KPQ_p - \Delta PQ_p$$

$$Cs.\ Y = \Delta PQ_c$$

where $Pr.\ Y$ is the change in producer income, $Cs.\ Y$ is the change in consumer expenditure in the market, ΔP is the change in price, Q_p is the quantity produced, Q_c is the quantity consumed, K is the unit cost reduction calculated as:

$$K = \left[\frac{E(G)}{\varepsilon} - \frac{E(C)}{1 + E(G)} \right] A_t$$

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[4] The approach essentially ignores small second round benefits associated with individual price response.

where $E(G)$ is the expected increase in yield per hectare, $E(C)$ is the proportionate change in variable costs per hectare, A_t is the expected adoption rate and ε is supply elasticity.[5] Changes in price after the introduction of the new technology can be easily calculated from elasticities of consumer demand (η), producer marginal cost (ε), and initial prices and quantities sold in each agroecological-drought risk zone. More specifically, assuming linear marginal cost and linear demand, the new price is:

$$P_1 = (\alpha - \gamma + KP_0)/(Q_0/P_0)(\eta + \varepsilon)$$

where α and γ are the intercepts of the linear marginal cost and the linear demand curves, respectively and Q_0 is the initial equilibrium quantity.

Transgenic varieties will most likely be a product of public-private partnerships with IPR protection on seed. Private sector profits are accounted for through a seed markup as in Falck-Zepeda et al. (2000). Specifically, assuming the seed company behaves as a monopoly in the seed market, profit is calculated as:

$$\Pi = (P_m - C) H$$

where P_m is monopoly price of seed to plant one hectare, C is the marginal cost of producing seed to plant one hectare, and H is the total cropped area. Most studies have assumed a constant marginal cost of seed per hectare (Qaim and De Janvry, 2003: Acquaye and Traxler, 2005: Falck-Zepeda et al., 2000). The price that maximizes monopoly's profits can then be found from Lerner's rule;

$$P_m = C / (1 + \eta^{-1})$$

where η is the elasticity of demand for seed. In the case of a seed markup, the K shift needs to be adjusted for changes in unit costs associated with the increased price of seed.

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[5] The elasticity of supply in the formulae for calculating K is assumed to be 1 as suggested by Alston, Norton, and Pardey (1995). The assumption of supply elasticity in the formulae for K is crucial for the overall magnitude of the benefits (Crawford and Oehmke, 2002).

Benefits of yield variance reduction

Yield variance reduction has been a priority of many crop improvement programs (Heisey and Morris, 2006). Methods for quantifying risk and transfer benefits associated with price variance reductions were developed by Newbery and Stiglitz (1981). However, to our knowledge, only Walker (1989) has attempted to quantify the economic benefits of yield variance reductions. He found very small risk benefits as a percentage of total producer income from completely eliminating the yield variance of one crop.

Our approach is different from the one in Newbery and Stiglitz (1981) in two important ways. First, as noted, a reduction in yield variance is examined, not a price stabilization scheme. Second, we use producer income and consumer income for each agroecological-drought risk zone, rather than export revenue, to evaluate producer and consumer risk benefits. In doing so, each zone is considered as a representative producer and consumer exposed to quantity variability, as well as ensuing price variability, at the market level. Under this specification, the representative producer has a Von-Newman Morgestern utility function of income $U(Y)$ with:

(1) $R = -YU''(Y)/U'(Y)$

where R is the coefficient of relative risk aversion. Producers are risk averse with respect to variations in incomes, and yield variability influences income variation. Specifically, transgenic research on drought tolerance will change the distribution of income from $\tilde{Y}_0$ with mean $\bar{Y}_0$ and coefficient of variation σ_{y0} to distribution $\tilde{Y}_1$ with mean $\bar{Y}_1$ and coefficient of variation σ_{y1}. The money value B for this reduction in income variation can be found by equating:

(2) $EU(\tilde{Y}_0) = EU(\tilde{Y}_1 - B)$

Expanding the left hand side using a Taylor series approximation we have:

(3) $$EU(\tilde{Y}_0) \cong U(\bar{Y}_0) + \frac{1}{2}E(\tilde{Y}_0 - \bar{Y}_0)^2 U''(\bar{Y}_0)$$

Similarly expand the right hand side:

(4) $$EU(\tilde{Y}_1 - B) \cong U(\bar{Y}_0) + (\Delta \bar{Y} - B)U'(\bar{Y}_0) + \frac{1}{2}E(\tilde{Y}_1 - \bar{Y}_0 - B)^2 U''(\bar{Y}_0)$$

Where $\Delta\bar{Y} = \bar{Y}_1 - \bar{Y}_0$

Equating (3) and (4), dividing by $\bar{Y}_0 U'(\bar{Y}_0)$ and neglecting terms of order higher than σ^2_{y1} the equation reduces to:

(5) $$\frac{B}{\bar{Y}_0} = \frac{\Delta\bar{Y}}{\bar{Y}_0} - \frac{1}{2}R(\overline{Y_0})\left\{\sigma^2_{Y1}\left(\frac{\bar{Y}_1}{\bar{Y}_0}\right) - \sigma^2_{Y0}\right\}$$

where the first term on the right hand side is what Newbery and Stiglitz (1981) refer to as transfer benefits and the second term is the risk benefit. If we focus solely on yield variance reductions, assuming mean income $\bar{Y}_0$ does not change, producer risk benefits are measured as:

(6) $$\frac{B}{\bar{Y}_0} = \frac{1}{2}R(\bar{Y}_0)\left\{\sigma^2_{Y0} - \sigma^2_{Y1}\right\}$$

Consumers may also benefit from a yield variance reduction through changes that variance of prices in each zone have on their expenditures. Applying the same methodology, the consumer risk benefits can be measured as:

(7) $$\frac{B}{\bar{X}_0} = \frac{1}{2}R(\bar{X}_0)\left\{\sigma^2_{p0} - \sigma^2_{p1}\right\}$$

where $\overline{X_0}$ is the mean consumer expenditure, σ^2_{p0} and σ^2_{p1} are the squared coefficient of variation of the crop prices before and after the yield variance reduction.[6] Two simplifying assumptions embodied in equations (6) and (7) are that the prices in other markets and producer and consumer income from other sources remain constant with the reduction in yield variation.

From equations (6) and (7) it is clear that the empirical estimation of risk benefits requires data on producer and consumer income, coefficients of variation of income and price, quantity produced, and the coefficient of relative risk aversion. Furthermore, the effect of the reduction in the variance of income from one crop on the variance of total producer income depends on the share of that crop in total producer income. Similarly, the effect of any changes in the variation of prices for a commodity on the variance of total consumer expenditure depends on the commodity share in total expenditure. Thus, we need to account for the share of each crop in total producer income. Specific assumptions are also needed on the shape of supply and demand curves to find the effects of yield variance reductions on price variability and, thus, producer income and consumer expenditure variability.

Results will also be sensitive to the source and type of risk (Newbery and Stiglitz, 1981). In this study we focus on the impact of technologies that reduce the variance of yields and the source of risk lies on the supply side. Two types of risks are usually employed in this type of analysis; additive and multiplicative risk. Here we use the most basic specification of additive supply risk with linear demand and supply curves. Let the initial demand and supply be specified as:

$$Q_d = \theta - \gamma P \quad (\gamma > 0) \tag{8}$$

$$Q_s = \alpha + \beta P \quad (\beta > 0) \tag{9}$$

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[6] Price variability is the only source of variability for consumer expenditures.

where Q_d and Q_s are quantity demanded and supplied, respectively. P is price, θ is a constant and α is a normally distributed random variable with mean μ_α and variance σ_α. Thus, demand is stable and supply fluctuates due to weather, technology, and other factors. Under linear supply and demand specifications equilibrium price and quantity are:

$$P = \frac{\theta - \alpha}{\gamma + \beta} \text{ and } Q = \frac{\theta\beta + \gamma\alpha}{\gamma + \beta}$$

Risk benefits with market price variability

Changes in the coefficient of variation of producer income can be found by comparing the difference in the variation of income with and without the yield variance reduction. Specifically, given demand and supply specifications, the variance of producer income is:

$$(10)\, Var(PQ) = Var\left[\left(\frac{\theta\beta + \gamma\alpha}{\gamma + \beta}\right)\left(\frac{\theta - \alpha}{\gamma + \beta}\right)\right] = E\left[\left\{\left(\frac{\theta\beta + \gamma\alpha}{\gamma + \beta}\right)\left(\frac{\theta - \alpha}{\gamma + \beta}\right)\right\}^2\right] - \left\{E\left(\frac{\theta\beta + \gamma\alpha}{\gamma + \beta}\right)\left(\frac{\theta - \alpha}{\gamma + \beta}\right)\right\}^2$$

$$= \left[\frac{(\theta^4\beta^2 - 2\theta^3\mu_\alpha\beta^2 + \theta^2\beta^2(\mu_\alpha^2 + \sigma_\alpha^2) + 2\theta^3\gamma\beta\mu_\alpha - 4\theta^2\gamma\beta(\mu_\alpha^2 + \sigma_\alpha^2) + 2\theta\beta\gamma(\mu_\alpha^3 + 3\mu_\alpha\sigma_\alpha^2)}{(\gamma + \beta)^4}\right] +$$

$$\left[\frac{(\theta^2\gamma^2(\mu_\alpha^2 + \sigma_\alpha^2) - 2\gamma^2\theta(\mu_\alpha^3 + 3\mu_\alpha\sigma_\alpha^2) + \gamma^2(\mu_\alpha^4 + 6\mu_\alpha^2\sigma_\alpha^2 + 3\sigma_\alpha^4)}{(\gamma + \beta)^4}\right] - \left[\frac{\sigma_\alpha^2\beta - \mu_\alpha\theta\beta + \mu_\alpha\theta\gamma - \gamma(\mu_\alpha^2 + \sigma_\alpha^2)}{(\gamma + \beta)^2}\right]^2$$

The yield variance reduction is incorporated into the analysis as a reduction in the variability of supply (i. e. as a reduction in σ_α). Specifically, if yield variance is reduced by a fraction z and the adoption rate of the technology is A, then, the new supply variability is $(1\text{-}z)A\ \sigma_\alpha$. Thus, changes in the variance of income are simulated by applying a reduction of (1-z) on the income variance for the agroecological-drought risk zones. Producer risk benefits can then be calculated using equation (6). Consumers also experience changes in the variation of their expenditures from yield variance reductions through changes in the variance of price. For the normal distribution, the variance of prices is:

$$(11) \qquad Var(P) = \left[\left(\frac{1}{\gamma + \beta} \right)^2 \sigma_\alpha^2 \right]$$

Changes in the variance of prices are, thus, easily recovered from changes in yield variance and consumer risk benefits can be calculated from equation (7).

Data description

Economic data

Economic data, including prices, elasticities of supply and demand, crop income and expenditure shares, and coefficients of relative risk aversion are obtained from several sources. Price data are from the FAO database (FAOSTAT, 2006). Quantity data are generated for each agroecological-drought risk zone in the manner discussed in section three.

Demand and supply elasticities influence the slope and intercept of the underlying linear demand and supply equations and, therefore, estimated changes in producer income and consumer expenditures. Ideally, zone specific elasticities would be used for the analysis. However, such disaggregated estimates are not available from the literature and country or region specific estimates are used instead. Since the analysis is interested in research benefits, and not additional benefits associated with price-induced investments in infrastructure, short-run supply and demand elasticities are employed based on previous estimates. In general, studies report inelastic short-run supply and demand elasticities for maize, rice, and wheat with absolute values between 0.1 and 0.6.

Estimates of demand and supply elasticities exist for all crops in India. Demand elasticities for maize, rice, and wheat in India are estimated by Kumar and Kumar (2003) as -0.31, -0.29, and -0.22, respectively. Chand and Jha (2001) use a supply elasticity of 0.43 for Indian wheat production. Further, maize and rice own-price area supply elasticities of 0.12 and 0.1 are used by Rosegrant et al. (2002). These demand and supply elasticities for India are employed in the analysis. Warr (2005) employs an elasticity of supply in the range of 0.186 – 0.434 for rice in Indonesia and Friedman and Levinsohn (2001) employ an elasticity of demand of -0.48. Therefore, we use a value of 0.32 for rice supply elasticity in Indonesia and a demand elasticity of -0.48. Maize supply and demand elasticities are not available for Indonesia and Philippines. In their absence we use a demand elasticity of –0.4 and a 0.3 supply elasticity. In the Philippines, the absolute value of rice demand elasticity has been estimated in the 0.23-0.47 range (Nasol, 1971) and supply elasticity has been estimated to be between 0.3 and 0.5 (Mangahas et al., 1974). Based on these two studies, elasticities of -0.35 and 0.4 are used for rice demand and supply, respectively in the Philippines. No estimates of elasticities of demand and supply are available for Bangladesh. Instead, we employ the 0.1 own-price area supply elasticity for wheat in South Asia of Rosegrant et al. (2002). Similarly, supply elasticities of 0.12 and 0.1 are assumed for maize and rice, respectively. Further, demand elasticities for maize, rice, and wheat are assumed to be the same in Bangladesh as for India.

Values of supply and demand elasticities for South Africa, Nigeria, Ethiopia and Kenya are also based on individual country studies or studies for Sub-Saharan Africa in general. These studies report elasticities of supply of 0.21 for wheat and 0.08 for maize in Ethiopia (Abrar, 2003), a supply elasticity of 0.2 for maize in Nigeria, a supply elasticity of 0.68 for maize in Kenya, and a demand elasticity of -0.4 for maize in Kenya (Kiori and Gitu, 1992). In the absence of other data wheat supply elasticities for South Africa, Nigeria and Kenya are considered the same as in Ethiopia. Further, demand and supply elasticities for rice in Kenya, and Nigeria, and rice and maize in South Africa are set to -0.3 and 0.35, respectively. Finally a -0.3 demand elasticity is assumed for wheat in Kenya, Nigeria, Ethiopia, and South Africa, based on estimates for all crops' price elasticities of demand and supply in Sub-Saharan Africa (Gabre-Madhin et al., 2002). The demand and supply elasticities for all crops and countries are summarized in table 2.

Producers generate income from a variety of sources including off-farm labor, capital, crops, and livestock. Estimates of maize, rice, and wheat income shares of total producer income are needed to assess the benefits of yield variance reductions. To recover this information, we rely on producer crop income shares for each country from different studies and then use the FAOSTAT database to assess the share of each crop in total producer income. Jayne et al. (2001) found crop shares of total income of 34 percent for Kenya, and 92 percent for Ethiopia. The share of crop income on total producer income for South Africa is assumed to be equal to the crop income share in Mozambique which is 85 percent (Jayne et al., 2001). Further, a crop income share of 55 percent is assumed for Nigeria based on the study by Reardon et al. (1992) for producers in drought prone zones in Burkina Faso. Since no estimates of the crop income shares of total producer income are available for any country in Asia, a 50 percent share on total producer income is assumed for India, Bangladesh, Philippines, and Indonesia.

Producer income shares for each crop are then derived from the FAOSTAT database value of agricultural production for each country in 2002. Table 3 reports the estimated share of producer income from each crop in each country. The shares vary widely across countries. The crop with the highest share in producer total crop income is rice in Bangladesh, followed by rice in Indonesia and The Philippines. Maize is also an important source of producer crop income in South Africa, Kenya, Ethiopia, and The Philippines. Wheat contributes 14 percent on producer crop income in India and 9 percent on producer crop income in Ethiopia and South Africa.

Consumer expenditures on maize, rice, and wheat as a share of total consumer expenditure are obtained from the Global Trade Analysis Project (GTAP) database (table 4). Consumer expenditures are not available for each African country. For Ethiopia and Nigeria consumer expenditure shares are assumed to be the same as those for the rest of Sub-Saharan Africa. Consumer expenditures for Kenya are assumed to be similar to those of neighboring Tanzania.

Newbery and Stiglitz (1981) provide a detailed discussion on the value of the coefficient of relative risk aversion. Based on experimental evidence they assume a maximum value of 1.2 for producers' R and a value of 1 for consumers' R. Considering that producers in this study are located in drought prone areas, the study employs this upper value of 1.2. Consumers are assumed to have an R equal to 1.

Technological Parameters

Drought related research benefits are very sensitive to expected mean yield increases. Transgenic research efforts to generate drought tolerant varieties of maize, rice, and wheat have prior estimates of expected yield increases, even though drought resistance has not been a priority of transgenic research. Expected yield increases used in this analysis are based on the results of three studies. Specifically, drought tolerant varieties produced from transgenic methods are assumed to increase mean maize yield by 18 percent based on a 10-23 percent yield increase estimated by Garg et al. (2002). Wheat mean yields are assumed to increase 25 percent, based on an increase of 30 percent in fresh weight under drought compared to traditional varieties in

Abebe et al. (2003). A 10 percent increase in mean yield is assumed for rice based on Quan et al. (2004), who found increases of 15 percent in photosynthesis efficiency. Other studies on transgenic research such as Sawahel (2004) and CIMMYT (2004) have also reported promising results.

Expected changes in variable input costs

Expected changes in variable costs are an important component of unit cost reductions. Drought resistant varieties from transgenic research are expected to influence variable costs through the seed markup charged to extract research benefits. The marginal cost of producing the seed is assumed to be constant in most of the studies that include seed markups (e.g. Qaim and De Janvry 2003; Falck-Zepeda et al. 2000; Hareau et al. 2005). Since transgenic research on drought tolerance is still in its early stages and there are no estimates on the marginal cost of seed, the marginal cost of transgenic maize, rice, and wheat seed are assumed equal to the seed costs per hectare currently paid by the farmers. Based on Hareau et al. (2005), the marginal cost of transgenic rice seed is assumed to be $35 per hectare. The marginal costs of transgenic maize and wheat seeds per hectare are assumed to be $25 and $20, respectively, based on shares of seed costs in total production costs (Khatun and Meisner, 2005). Obviously, the profit of the monopolist depends on both seed markup and adopted area. Therefore, to find the profit of the company we need the elasticity of the demand for seed and also the equilibrium price and the area planted. In previous empirical work Acquaye and Traxler (2005) find the demand elasticity of seed to be -2.1 and Qaim and De Janvry (2003) find demand elasticities of -4.8 at a price of $103 and -13.1 at prices of $95 per hectare of Bt cotton seed. In this study, the seed demand elasticity is assumed to take a minimum value of -2.0, a most likely value of -4.0, and a maximum value of -6.0 for all three crops. Further, it is assumed that the patent holder behaves as a monopolist in the seed market. Thus, potential profits are calculated under the three different elasticities based on the assumed adoption rate for each crop.

The seed markup also influences unit production costs by increasing average costs per hectare of cropped area. Khatun and Meisner (2005) in their study for Bangladesh estimate average total costs of \$586, \$396 and \$603 per hectare for maize, wheat and rice, respectively. Hareau et al. (2005) estimate an average total cost of \$657 per hectare for rice in Uruguay. In the current study a total cost of \$630 per hectare is assumed for rice and the estimates of Khatun and Meisner (2005) are used for maize and wheat.

Yield variability and expected variance reductions

Initial yield variability is a crucial parameter for assessing the economic impacts of yield variance reducing technologies. Studies based on drought prone areas have found high coefficients of yield variation. Walker (1989) found coefficients of variations of 0.66 and 0.68 for sorghum on drought prone areas of India. Reardon et al. (1982) found coefficients of yield variation of 0.74 for millet and 0.51 for sorghum in drought risk areas of Burkina Faso.

Based on the findings by Walker (1989) and Reardon et al. (1992) we assume conservative coefficients of yield variation of 0.5 for all three crops in high drought risk zones and a coefficient of yield variation of 0.3 in the low-medium drought risk zones. Specific data on potential yield variance reductions are not available. Transgenic research is regarded as one of the most powerful tools in improving agricultural productivity. Thus, we assume potential reductions of 25 and 15 percent in yield variance for high and low-medium drought risk zones, respectively.

Adoption Rates

Previous studies show that adoption rates depend on the extra costs that the farmers have to incur in order to adopt the new method. Transgenic drought resistant varieties will induce some extra costs to farmers in terms of higher seed prices and are assumed to have adoption rates of 45 and 15 percent in high and low-medium drought risk zones, respectively. These estimates are conservative when compared to other studies on adoption rates of high yielding varieties of maize, rice, and wheat which have found adoption rates of up to 72 percent for improved wheat varieties (Zegeye et al., 2000), adoption rates of up to 70 percent for improved maize varieties (Morris et al., 1999), and adoption rates of up to 68 percent for improved rice varieties (Saka et al., 2005).

Results

Simulated ex-ante benefits from transgenic research in maize, rice, and wheat across the rain-fed agroecological-drought risk zones are calculated for each country. Disaggregated research benefits for each agroecological-drought risk zone in India are presented in table 5 as an example.[7] The table reports changes in producer income (Pr. Y), changes in consumer income (Cs. Y), and profits to the private sector (Π*)* along with risk benefits to producers (Ps. RB) and consumers (Cs. RB) from yield variance reductions. All values are in thousands of U.S. dollars. The ex-ante benefits cover one planting year and are generated employing the expected adoption rates, mean yield increases, yield variance reductions and the other parameters discussed in the previous section.

Results in table 5 suggest that transgenic research mean yield increases can generate substantial benefits for the seven agroecological-drought risk zones of India. Benefits from

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[7] Ex-ante benefits for the agroecological-drought risk zones of the other seven countries are available upon request.

transgenic research mean yield increases in maize, rice, and wheat in India are concentrated in the four zones in warm tropic and sub-tropic areas where most of the rain-fed agricultural production takes place. The size of the benefits appears promising not only for producers and consumers, but also for the private sector. The distribution of benefits suggests that producers are the main beneficiaries from mean yield increases in maize and rice, and consumers are the main beneficiaries from mean yield increases in wheat. The private sector gains the most from transgenic research generated mean yield increases in rice.

Yield variance reductions from transgenic research also appear to generate substantial benefits. In fact, maize producers and consumers, and rice producers and consumers in the high drought risk zones of India gain more from yield variance reductions than from mean yield increases. For wheat, the benefits to producers and consumers from mean yield increases are greater than the benefits from yield variance reductions in both low-medium and high drought risk zones. Overall, the sum of benefits from yield variance reductions for maize and rice producers and consumers are greater than the sum of benefits from mean yield increases. However, the converse is true for wheat. Aggregate benefits across zones for India suggest that transgenic drought research on rice will generate the largest social benefits, followed by wheat and then maize.

Aggregate benefits for all eight countries are presented in table 6. The results demonstrate that substantial social benefits can be generated from both mean yield increases and yield variance reductions associated with transgenic drought tolerance research. Consumers and producers across all eight countries are estimated to gain a total of $418 million and $399 million, respectively. The potential gains from mean yield increases are - in aggregate - larger than gains from yield variance reductions. Nevertheless, gains from yield variance reductions for producers and consumers sum up to $178 million and $190 million, respectively. Furthermore, the estimated benefits from yield variance reductions are greater than the benefits generated from mean yield increases within some countries and for some crops, most notably rice in Bangladesh and India.

Results suggest that transgenic research in maize has the potential to generate most ex-ante benefits for producers and consumer in the agroecological-drought risk zones of South Africa who gain $73 million and $93 million, respectively. Substantial benefits accrue also to producers and consumers in Nigeria with total gains of $82 million. In general, producers and consumers in African countries benefit more than maize producers and consumers in Asia from transgenic maize drought research. Profits to the private sector from maize research are also substantial, especially in South Africa, Nigeria, and India with profits of $12 million, $7 million, and $5 million, respectively.

As expected, rice transgenic drought research benefits are greater for the producers and consumers in India as a result of a larger rice planted area compared to rest of the countries. As rice is not a popular crop among producers in Africa, ex-ante rice research benefits in Kenya, Ethiopia, and South Africa are either zero or negligible. However, there are considerable benefits to produces and consumers in Nigeria who gain a total of $48 million. In fact, rice drought research benefits in Nigeria are larger than the benefits in Indonesia and Philippines. Transgenic drought tolerance research also generates sizeable profits to the private sector, most notably in India with private sector profits of $28 million.

Wheat drought research benefits are also substantial, especially for the producers and consumers in India with total gains of $29 million and $53 million, respectively, and producers in South Africa with benefits of $30 million. Private sector profits from transgenic drought tolerance research in wheat across all eight countries are $11 million. Thus the private sector gains estimated profits of $93 million across all three crops.

Several important factors influence the distribution and the magnitude of expected benefits in this analysis. First, the distribution of potential benefits from drought tolerance research among producers and consumers in each agroecological-drought risk zone depends on the elasticities of supply and demand employed with producers (consumers) experiencing the largest gains if supply is relatively less (more) elastic than demand. Second, the magnitude of expected benefits from yield variance reductions is sensitive to the demand and supply elasticities employed in the study. Specifically, benefits from yield variance reductions to producers and consumers decrease with increases in the absolute value of demand elasticity and the value of supply elasticity. For example, the total producer and consumer benefits from maize yield variance reductions in the low-medium and high drought risk zones of India are initially $12 million and $13 million, respectively, using a demand elasticity of -0.32 and a supply elasticity of 0.12. Simulations with an elasticity of supply of 0.3 (keeping the elasticity of demand at -0.32) generate total consumer risk benefits of $4 million and total producer risk benefits of $3 million. Similarly, a demand elasticity of -0.4 (keeping supply elasticity constant at 0.12) generates total consumer risk benefits of $9 million and total producer risk benefits of $8 million. Finally, the magnitude of private sector profits is particularly sensitive to the seed demand elasticity employed. Estimated ex-ante benefits with the most likely value of seed demand elasticity of -4.0 suggest that in most cases producers are the main beneficiaries from transgenic research on drought tolerant varieties, followed by consumers and the private sector. However, for a seed demand elasticity of -2.0, the private sector shows the largest gains from transgenic rice drought resistant varieties in India and Bangladesh and from maize drought resistant varieties in Philippines, Kenya, and Nigeria. Thus, private sector profits increase (decrease) substantially as seed demand elasticity decreases (increases). Conversely, the sensitivity analysis indicates that producer and consumer potential benefits increase as the seed demand elasticity increases.

6. Conclusions

The estimated ex-ante transgenic drought tolerance research benefits for maize, rice, and wheat are substantial. Transgenic research for drought resistance is still in its infancy but initial results appear very promising for the millions of poor in the more marginal rain-fed agricultural areas of developing countries. Further, estimated annual benefits of $US 93 million to the private sector from the generation of drought tolerant transgenic varieties in the eight low-income countries suggests that significant incentives exist for public-private partnerships to foster transgenic drought tolerant research in major cereal crops. Large overlaps in agroecological-drought risk zones suggest that substantial scope also exists for inter-country collaboration in drought tolerance research and sharing of spillovers from both public and private investments. For example, the largest total benefits of $202 million are generated in the humid/sub-humid low-medium drought risk zone in the warm tropics and sub-tropics which is common across the eight countries. Finally, risk benefits from yield variance reductions are demonstrated to be an important component of aggregate drought research benefits, representing 41 percent of total benefits. These benefits are often overlooked in conventional ex-ante analyses. More refined parameterization of potential variance reductions and other parameters that underlie these benefits is an important area for further research.

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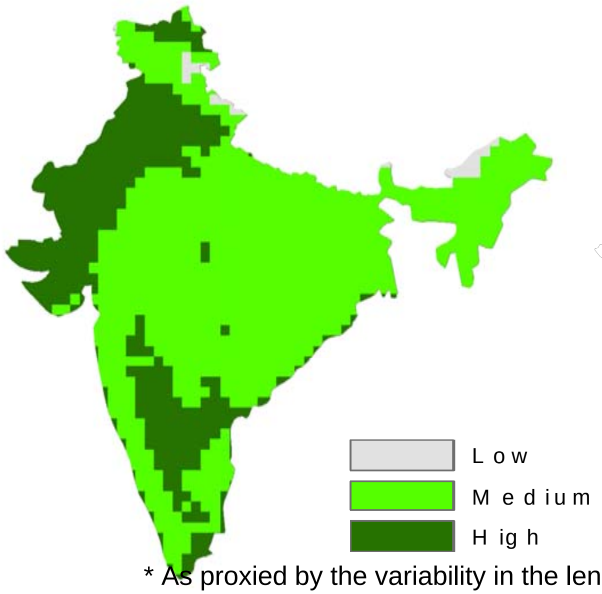
Panel 1: India

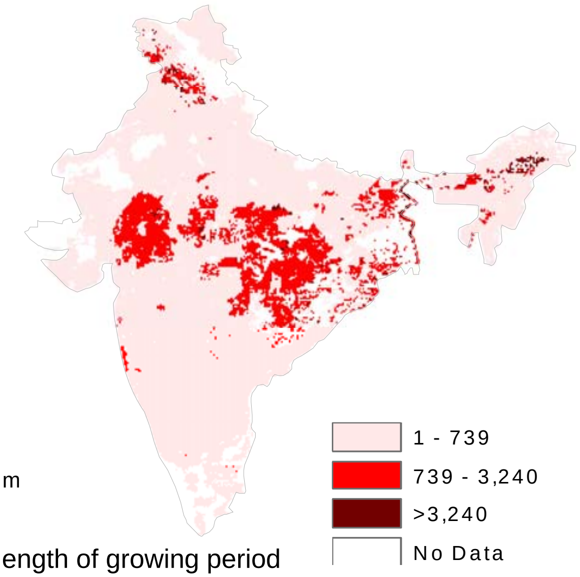
Drought Risk*



* As proxied by the variability in the length of growing period

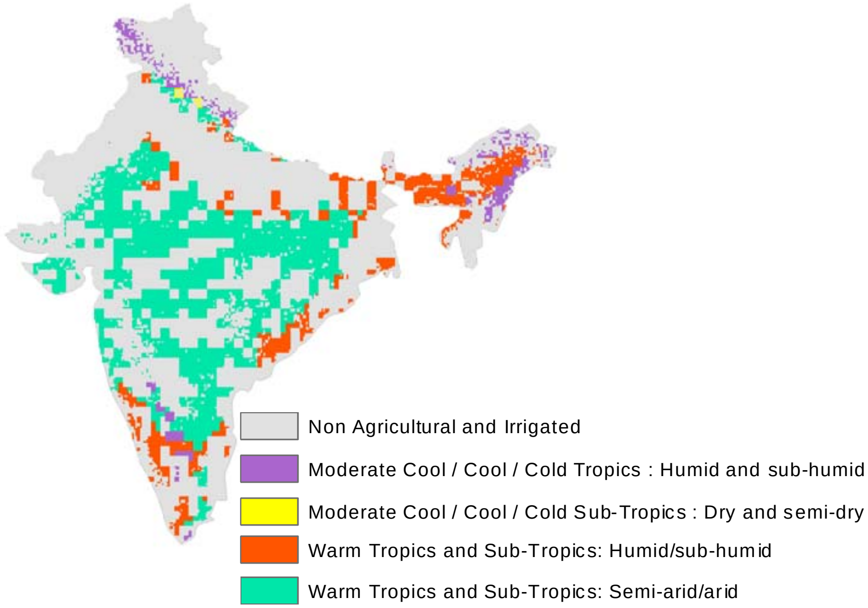
Source: Adapted from Fischer et al. 2002

Rain-fed Cropped Area (ha/pixel)



Source: IFPRI 2006

Agroecological Zones



Source: Wood et al. 2000

India: Agroecological-Drought Risk Zones

	Maize (ha)	Maize (mt)	Yield (mt/ha)	Rice (ha)	Rice (mt)	Yield (mt/ha)	Wheat (ha)	Wheat (mt)	Yield (mt/ha)
MODERATE COOL/COOL/COLD TROPICS AND SUB-TROPICS									
Humid/sub-humid: Low – Med Risk	232,616	313,184	1.35	163,212	364,725	2.23	114,798	280,882	2.45
Humid/sub-humid: High Risk	46,042	75,421	1.64	96,846	326,097	3.37	50,035	111,344	2.23
Dry and semi-arid: High Risk	11,041	11,269	1.02	12,693	9,208	0.73	16,209	36,167	2.23
WARM TROPICS AND SUB-TROPICS									
Humid/sub-humid: Low – Med Risk	502,606	1,026,611	2.04	5,025,174	9,758,196	1.94	872,447	1,878,666	2.15
Humid/sub-humid: High Risk	52,233	162,619	3.11	299,480	935,678	3.12	228,714	723,329	3.16
Semi-arid/arid: Low - Med Risk	1,848,746	2,384,834	1.29	5,622,930	8,567,506	1.52	2,713,237	4,216,830	1.55
Semi-arid/arid: High Risk	397,562	546,761	1.38	701,769	2,064,960	2.94	689,709	1,480,949	2.15

Table 1. Maize, Rice, and Wheat Production across the Rain-fed Agroecological-drought Risk Zones (thousands)

MAIZE

	Bangladesh		**India**		**The Philippines**		**Indonesia**		**Kenya**		**Nigeria**		**Ethiopia**		**South Africa**	
	mt	ha	mt	ha	mt	ha	mt	ha	mt	ha	mt	ha	mt	ha	mt	ha
MODERATE COOL/COOL/COLD TROPICS AND SUB-TROPICS																
Humid/sub-humid: LM Risk			313	233					661	401	0.1	0.1	2456	1363	698	203
Humid/sub-humid: H Risk			75	46					877	673			239	91	6796	2476
Dry and semi-arid: LM Risk															105	54
Dry and semi-arid: H Risk			11	11											1129	401
WARM TROPICS AND SUB-TROPICS																
Humid/sub-humid: LM Risk	3	2	1027	503	2991	1645	2607	806	264	191	627	694	121	78	7	2
Humid/sub-humid: H Risk			163	52	83	47	9	6					14	13	120	32
Semi-arid/arid: LM Risk			2385	1849			152	35			3559	3256	19	22		
Semi-arid/arid: H Risk			547	398					37	28	799	607	30	7	427	106

RICE

	Bangladesh		**India**		**The Philippines**		**Indonesia**		**Kenya**		**Nigeria**		**Ethiopia**		**South Africa**	
MODERATE COOL/COOL/COLD TROPICS AND SUB-TROPICS																
Humid/sub-humid: LM Risk			365	163					21	5	1	1				
Humid/sub-humid: H Risk			326	97					26	5					1	0.5
Dry and semi-arid: LM Risk																
Dry and semi-arid: H Risk			9	13											0.2	0.1
WARM TROPICS AND SUB-TROPICS																
Humid/sub-humid: LM Risk	15428	4303	9758	5025	3883	1335	10327	2267	1	6	513	670			0.3	0.2
Humid/sub-humid: H Risk			936	299	150	39	46	16								
Semi-arid/arid: LM Risk			8568	5623			127	23			3137	2996				
Semi-arid/arid: H Risk			2065	702					0.13	5.41	638	560			0.11	0.05

WHEAT

	Bangladesh		**India**		**The Philippines**		**Indonesia**		**Kenya**		**Nigeria**		**Ethiopia**		**South Africa**	
MODERATE COOL/COOL/COLD TROPICS AND SUB-TROPICS																
Humid/sub-humid: LM Risk			281	115					160	96	0.7	0.4	1324	936	185	96
Humid/sub-humid: H Risk			111	50					46	19			76	51	1452	653
Dry and semi-arid: LM Risk															21	5
Dry and semi-arid: H Risk			36	16											139	74
WARM TROPICS AND SUB-TROPICS																
Humid/sub-humid: LM Risk	379	213	1879	872							14	10				
Humid/sub-humid: H Risk			723	229											37	21
Semi-arid/arid: LM Risk			4217	2713							64	45	16	25		
Semi-arid/arid: H Risk			1481	690							16	11	0.2	0.2	69	35

Note: LM = Low-Medium, H = High.

Table 2. Own-price Demand and Supply Elasticities in Each Country

	Maize		Rice		Wheat	
	Demand	Supply	Demand	Supply	Demand	Supply
India	-0.31	0.12	-0.29	0.1	-0.22	0.43
Indonesia	-0.4	0.3	-0.48	0.32	-	-
Bangladesh	-0.31	0.12	-0.29	0.1	-0.22	0.1
Philippines	-0.4	0.3	-0.35	0.4	-	-
Kenya	-0.4	0.68	-0.3	0.35	-0.3	0.21
Nigeria	-0.3	0.2	-0.3	0.35	-0.3	0.21
Ethiopia	-0.3	0.08	-	-	-0.3	0.21
S. Africa	-0.3	0.35	-0.3	0.35	-0.3	0.21

Table 3. Producer Income from Maize, Rice, and Wheat Income as a Share of Total Crop Income (percentages)

	Maize	Rice	Wheat
India	1.7	18.8	14.4
Indonesia	0.3	31.5	0.0
Philippines	7.6	31.2	0.0
Bangladesh	0.3	71.9	4.1
Ethiopia	9.7	0.0	8.7
Kenya	14.6	0.4	2.3
Nigeria	3.3	3.2	0.1
South Africa	24.9	0.0	8.6

Table 4. Consumer Expenditure on Maize, Rice, and Wheat as a Share of Total Expenditure (percentages)

	Maize	Rice	Wheat
India	1.0	5.3	3.1
Indonesia	0.6	4.4	0.2
Bangladesh	0.1	17.0	0.7
Philippines	1.6	6.5	0.8
South Africa	0.6	0.3	0.3
Kenya	12.3	1.8	1.3
Ethiopia	4.1	5.0	1.1
Nigeria	4.1	5.0	1.1

Table 5. Potential Benefits from Transgenic Research Mean Yield Increases and Yield Variance Reductions in India (thousands U.S. dollars)

Benefits from mean yield increases										
		Maize			Rice			Wheat		
Agroecological-Drought Risk Zones		Pr. Y	Cs. Y	Π	Pr. Y	Cs. Y	Π	Pr. Y	Cs. Y	Π
Moderate Cool/Cool/ Cold Tropics and Sub-Tropics	Humid/sub-humid: Low-Med risk	634	246	291	395	136	286	476	931	115
	Humid/sub-humid: High risk	459	178	173	1,060	365	508	569	1,113	150
	Dry and semi-arid: High risk	69	27	41	30	10	67	185	361	49
Warm Tropics and Sub-Tropics	Humid/sub-humid: Low-Med risk	2,079	805	628	10,561	3,642	8,794	3,186	6,226	872
	Humid/sub-humid: High risk	990	383	196	3,041	1,049	1,572	3,699	7,229	686
	Semi-arid/arid: Low-Med risk	4,830	1,870	2,311	9,272	3,197	9,840	7,150	13,976	2,713
	Semi-arid/arid: High risk	3,329	1,289	1,491	6,711	2,314	3,684	7,573	14,801	2,069
Benefits from yield variance reductions										
Agroecological-Drought Risk Zones		Pr. RB	Cs. RB		Pr. RB	Cs. RB		Pr. RB	Cs. RB	
Moderate Cool/Cool/ Cold Tropics and Sub-Tropics	Humid/sub-humid: Low-Med risk	217	293	-	360	454	-	45	61	-
	Humid/sub-humid: High risk	937	934	-	5,834	5,376	-	246	320	-
	Dry and semi-arid: High risk	140	140	-	165	152	-	80	104	-
Warm Tropics and Sub-Tropics	Humid/sub-humid: Low-Med risk	711	959	-	9,636	12,134	-	304	407	-
	Humid/sub-humid: High risk	2,020	2,014	-	16,740	15,424	-	1,601	2,079	-
	Semi-arid/arid: Low-Med risk	1,651	2,228	-	8,460	10,653	-	682	914	-
	Semi-arid/arid: High risk	6,791	6,771	-	36,943	34,040	-	3,278	4,257	-
Sum of total benefits		24,857	18,137	5,131	109,208	88,946	24,751	29,074	52,779	6,654

Note: Elasticity of seed demand is -4.0.

Table 6. Potential Annual Benefits from Transgenic Research Mean Yield Increases and Yield Variance Reductions in All eight Countries (thousands U.S. dollars)

		BGD	**IND**	**PHI**	**IDO**	**KEN**	**NIG**	**ETH**	**SOA**
Maize	Pr. Y	8	12,390	5,816	5,681	5,929	25,237	4,136	48,708
	Cs. Y	3	4,798	4,363	4,260	10,079	16,825	1,724	56,825
	Π	3	5,131	3,127	1,074	3,374	7,216	2,242	11,629
	Pr. RB	3	12,467	537	409	166	17,536	5,093	24,603
	Cs. RB	4	13,339	1,018	813	374	22,121	5,025	35,963
Rice	Pr. Y	16,325	31,070	6,095	9,859	133	14,331	-	9
	Cs. Y	5,629	10,713	3,153	7,669	156	16,721	-	10
	Π	7,531	24,751	2,536	4,093	38	9,361	-	3
	Pr. RB	14,894	78,138	717	850	116	6,639	-	6
	Cs. RB	18,756	78,233	1,287	2,121	170	9,955	-	9
Wheat	Pr. Y	1,348	22,838	-	-	1,348	1,121	4,048	23,279
	Cs. Y	613	44,637	-	-	944	785	2,835	16,295
	Π	213	6,654	-	-	153	87	1,114	2,451
	Pr. RB	779	6,236	-	-	631	461	1,028	6,506
	Cs. RB	874	8,142	-	-	798	589	1,391	9,512

Note: BGD = Bangladesh, IND = India, PHI = The Philippines, IDO = Indonesia, KEN = Kenya, NIG = Nigeria, ETH = Ethiopia, SOA = South Africa.