Three Essays on Measuring the Ex-ante Economic Impacts of Agriculture Technology Innovations

Introduction

Technology innovations in agriculture have achieved important milestones during the last two decades. For instance advances in biotechnologies and breeding continue to increase agricultural productivity. Biopharming, for example, is a promising new field with pharmaceutical companies producing proteins of great medical value at a fraction of their current production costs. Several biopharmaceutical companies have already tested these products successfully and started clinical trials. CaroRX, for example, is a plant-produced treatment for dental caries which is already approved for sale in Europe and is undergoing stage II clinical trials in the U.S.

However, despite its wide applications, biotechnology is mainly used by the private sector in markets with well-established intellectual property rights (IPRs) that enable private sector firms to appropriate research investments. Thus, biotechnology has primarily benefited developed or transition economies where concerns are not necessarily the same as those in low-income countries. For example, drought is still a problem for many subsistence farmers in the low-income countries. Conventional breeding efforts to develop drought resistant varieties have successfully released several important maize, rice, and wheat varieties. Breeding through biotechnology has also been identified as a powerful tool to mitigate drought losses (CGIAR, 2003; FAO, 2003; Doering, 2005). There have been very few attempts to develop transgenic drought resistant varieties in Sub-Saharan Africa or other regions highly susceptible to drought. Yet, nineteen out of the 25 world's poorest countries are found in Sub-Saharan Africa where income inequality is high (Dixon, Gulliver, and Gibbon, 2001).

While biopharming and drought research can potentially deliver larger economic benefits, the magnitude and the distribution of such benefits remain, to date, largely unknown. Ex-ante analyses of the economic impacts associated with biopharming and drought research in low-income countries may provide useful insights not only to producers and consumers, but also to policy makers. This dissertation is comprised of three papers that use innovative methods to measure the magnitude and distribution of the ex-ante economic impacts of agriculture technology innovations.

The first paper entitled “Valuing Intellectual Property Rights in an Imperfectly Competitive Market: A Tobacco Biopharming Application” examines the ex-ante value of intellectual property rights (IPRs) for a biotech firm that obtains a patent on the production process of Glucocerebrosidase enzyme (Gaucher’s disease treatment) from transgenic tobacco. With the emergence of biopharming, small research biopharmaceutical firms usually establish IPRs on innovative processes that can then be sold to larger firms with existing market channels. For example, in 2005, the value of the top ten acquisitions and product alliances between large pharmaceutical companies and biotech firms was $15 billion (Zimm, 2007). But these mergers and acquisitions are examined by antitrust institutions in the U.S. to ensure that they do not lessen competition or tend to create a monopoly. The acquisitions of Astra by Zeneca (1999) and of Marion Merrell Dow by Hoechst (1995) are examples of proposed mergers that potentially inhibited new competition and were blocked by the U.S. Federal Trade Commission (FTC) under the Calyton Act of 1914.

In the paper, the current market for Gaucher’s disease treatment is served by one firm, Genzyme, which has the most efficient pre-innovation process of production. Genzyme, might potentially offer the ‘highest’ price for the innovator’s IPRs, but acquisition by the incumbent is likely a violation of the Clayton Act and would be considered illegal by the FTC. Thus we employ Cournot and Stackelberg strategies to determine the value of IPRs to the innovator based on the expected profit stream from competition with the current monopolist. Production process, patent life, and the emergence of fringe competition after patent expiration are considered in estimating the potential profit stream and consumer welfare benefits from the innovation.

The second paper in my dissertation entitled "Ex-Ante Analysis of the Benefits of Transgenic Drought Tolerance Research on Cereal Crops in Low-Income Countries" examines ex-ante impacts of transgenic research to mitigate drought in maize, rice, and wheat in the rain-fed areas of India, Indonesia, Bangladesh, The Philippines, Kenya, Ethiopia, Nigeria, and South Africa. Drought has been recognized as one of the most costly threats to agriculture with average annual production losses of rice and maize in tropical areas estimated at around $US 7 billion per year (Doering, 2005).

While past research has focused almost exclusively on benefits generated by expected mean yield increases, the present study also estimates the benefits of yield variance reductions as measured by risk reduction to producers and consumers. Such variance reductions are often the main goal of drought tolerance research. For example, Traxler et al. (1995) find that the post Green Revolution shift in the distribution of wheat yields is characterized by a relatively rapid improvement in yield stability and slow mean yield growth. The method generated in the paper employs a spatial framework that identifies country-specific agroecological-drought risk zones and considers both yield increases and yield variance reductions when estimating producer and consumer benefits from research. The results shed light on the relative magnitude of the benefits from mean yield increases and yield variance reductions generated by drought tolerance research, as well as the incentives potential seed markups create for private sector involvement in transgenic research on drought tolerance in major crops.

One of the main objectives of agricultural policies and technologies in low-income countries is to improve the well-being of the poor households. Thus, when evaluating agricultural technology innovations in low-income countries, it is important to disaggregate the impacts among different types of households. The third paper in my dissertation entitled "Ex-Ante Evaluation of Alternative Strategies to Increase the Stability of Cropping Systems in Eastern and Central Africa" examines the benefits of stabilizing agricultural incomes through new crop varieties that enhance productivity and reduce yield variability under drought conditions. The analysis is applied to three major cereal crops, maize, sorghum, and millet, in Kenya, Uganda and the Amhara region in Ethiopia.

Existing household surveys for each country are analyzed to create three types of representative maize, millet, and sorghum producing households (e.g., small, medium, and large) that characterize production in the rainfed drought risk zones of Kenya, Ethiopia, and Uganda. A literature review and expert opinion process is used to collect information on potential drought-resistant varieties as well as other parameters needed to carry out the empirical analysis.

The monetary welfare gains of representative households associated with stabilizing income by adopting more drought-resistant varieties are evaluated using an expected utility framework. Benefits are then aggregated to the regional and country level.

Results suggest that estimated ex-ante benefits from yield variance reductions can be an important part of drought related research with potential benefits similar to those from mean yield increases, especially in the medium and high drought risk areas. Large producers in the rainfed regions of Kenya, Uganda and the Amhara region in Ethiopia benefit the most from drought research in maize, millet and sorghum. However, small and medium maize, millet and sorghum farmers also gain substantial benefits from both mean yield increases and yield variance reductions. This type of framework can be easily adapted to other cases where policy makers seek market level as well as household type level benefits.

Overall, private sector maize drought research seems to be the most beneficial, however, transgenic drought resistant varieties have yet to pass regulatory approvals before they reach the seed markets in developing countries. Meanwhile, public sector research on drought resistance appears to be very promising for the farmers in the drought prone areas of the ASARECA region.

All three papers in this dissertation generate innovative methods to document the ex-ante impact of agriculture technology innovations. The results are expected to provide valuable information on the ex-ante benefits of biopharming and drought tolerant research.

References

CGIAR. 2003. “Applications of Molecular Biology and Genomics to Crop Tolerance and Abiotic Stresses. A Discussion Document.”

Doering, D. S. 2005. ”Public-Private Partnerships to Develop and Deliver Drought-tolerant Crops to Food-Insecure Farmers.” CGIAR.

FAO. 2003. “Which Road Do We Take”? Harnessing Genetic Resources and Making Use of Life Sciences, a New Contract for Sustainable Agriculture.”

Dixon, J. Gulliver, A., and D. Gibbon. 2001. Farming Systems and Poverty: Improving Farmers’ Livelihoods in a Changing World. FAO and World Bank Rome and Washington D.C.

Robson, A. J., 1990. “Stackelberg and Marshall.” American Economic Review 80: 69–82.

Traxler, G., Falck-Zepeda, J., Ortiz-Monasterio, R. J. I., and K. Sayre. 1995. “Production Risks and the Evolution of Varietal Technology.” American Journal of Agricultural Economics 77:1-7.

Zimm, A., 2007. Biotech firms become more tempting targets. The Philadelphia Inquirer. Retrieved on January 15, 2008 from World Wide Web: http://www.philly.com/mld/inquirer/business/16461995.htm.

Essay 1

Valuing Intellectual Property Rights in an Imperfectly Competitive Market: A Biopharming Application

Introduction

Small research firms in the biopharmaceutical industry commonly strive to establish intellectual property rights (IPRs) on innovative technologies that can then be sold to larger firms with existing market channels. For example, in 2005, the value of the top ten acquisitions and product alliances between large pharmaceutical companies and biotech firms was $15 billion (Zimm, 2007). In 2004 the large pharmaceutical company Pfizer paid $1.3 billion for Esperion Therapeutics, a small firm with a drug that boosts levels of "good" cholesterol (Alpert, 2004). In 2003, companies paid over $5 billion for six biotech firms (Alpert, 2004). In 2001 Amgen Inc., a large biotech company bought Immunex Corp. with its very successful drug Enbrel for about $16 billion (Gillis, 2002), while in 2000 a total of $2.7 billion was paid by pharmaceutical companies for seven biotech acquisitions.

Usually small biotech firms generate biopharming applications to produce lower cost drugs for markets that are currently served by just a few (or only one) firms with substantial market power. At the same time, in the U.S. antitrust laws prohibit mergers and acquisitions if they substantially lessen competition, or tend to create a monopoly (Clayton Act 1914).[1] The acquisitions of Astra by Zeneca (1999) and of Marion Merrell Dow by Hoechst (1995) are examples of proposed mergers that potentially inhibited new competition and were blocked by the U.S. Federal Trade Commission (FTC) (Balto and Mongoven, 1999). Thus, FTC regulations

[1] Patent acquisition by an incumbent with market power would not need to be reported in the Federal Trade Commission (FTC) under the Hart-Scott-Rodino Act of 1978, but still would be a violation of Section 7 of the Clayton Act if the patent were the major asset of the innovator and its acquisition reduced future competition.

requiring that buyers of small biotech firms be non-participants in the intended market suggest the acquiring firm will enter as an oligopolist.

In this paper we assume an innovator enters the market using a Cournot or Stackelberg strategy to estimate the potential ex-ante value of IPRs for a small biotech firm in an imperfectly competitive market. While a vast literature exists on the emergence of Cournot and Stackelberg strategies in oligopoly markets (e.g. Kreps and Scheinkman, 1983; Saloner, 1987; Allen, 1992; Hamilton and Slutsky, 1990; Robson, 1990; Qin and Stuart, 1997; Tasnadi, 2006), to our knowledge, these strategies have not been employed in ex-ante IPRs evaluations of process innovations, especially in the presence of antitrust laws. Specifically, the value of IPRs is estimated for the case of an innovating firm that obtains a patent on the production of Glucocerebrosidase enzyme (Gaucher's disease treatment) from transgenic tobacco. The current market for Gaucher's disease treatment is served by one firm, which has the most efficient pre-innovation process of production. Genzyme, might potentially offer the 'highest' price for the innovator's IPRs, but acquisition by the incumbent is likely a violation of the Clayton Act and would be considered illegal by the FTC.[2] Therefore, Cournot and Stackelberg duopolist strategies are employed to determine the value of IPRs to the innovator based on the expected profit stream from competition with the current monopolist. Both production process patent life and the emergence of fringe competition after patent expiration are considered in estimating the potential profit stream.[3] In addition, consumer welfare effects are calculated and the results are

[2] Genzyme has the strongest incentives to obtain the innovator's IPRs, since it can retain the monopoly position and reduce some of the losses incurred if the innovator or a firm acquiring the innovator's IPRs enters the market.
[3] Generic competition may lead to prominent revenue losses for drug companies whose patents expire. For example, Pfizer may lose almost half of its $51 billion in 2005 sales as a result of emerging competition from generic-drug makers to products with expiring patents (Zimm, 2007). Similarly, Merck, the fourth-largest U.S. drugmaker, may lose $3 billion in sales this year from its top-selling Zocor cholesterol pill because of generic competition (Zimm, 2007).

contrasted with the scenario where the innovator's production process is acquired by the current sole market participant; Genzyme.

The rest of the paper is organized as follows. Section two provides background information on biopharming, Gaucher's disease, and the Cerezyme market. The model used to determine the value of the IPRs and welfare changes is presented in the third section. The therapeutic protein production process, unit cost reductions, and other data used in the model are presented in section four and ex-ante benefits are provided in section five. Section six concludes.

Background on Biopharming, Gaucher's Disease and the Cerezyme Market

Biopharming and transgenic tobacco

Genetic engineering of plants and animals holds the promise to produce therapeutic protein drugs at significantly lower costs than current pharmaceutical production methods.[4] For example, empirical studies of biopharming show 10-100 times lower production costs when compared to cell culture systems (Misson and Curling, 2000: Kusnadi et al., 1997).[5] Further, transgenic plants are generally preferred to transgenic animals for biopharming since they are safer (by not hosting mammalian pathogens) and structurally more fit to produce complex proteins (Cramer et al., 1996).[6] Plant-produced proteins research is being conducted on a variety of agricultural crops such as corn, tobacco, potato, alfalfa, rice, and canola. Some biotech companies such as Large Scale Biology Corp. and Planet Biotechnology Inc. have targeted tobacco as a prospective production engine. Tobacco is considered to be safer than other

[4] Protein drugs are the fastest growing area in the pharmaceutical industry.
[5] Cell culture systems are the current method of protein production in the pharmaceutical industry where the targeted protein is produced by genetically engineering mammalian or bacterial cells.
[6] Transgenic plants refer to genetically modified plants.

potential candidates because of reduced risk of contaminating the food supply or other non-genetically modified tobacco.[7]

Research on tobacco has already achieved remarkable results and therapeutic proteins from transgenic tobacco are expected to be among the first marketed plant-produced medicines. Many biotech firms are now conducting clinical trials with proteins of plant origin, indicating that commercialization is not far. CaroRX, for example, is a treatment for dental caries which is already approved for sale in Europe and it is undergoing stage II U.S. clinical trials.

Gaucher's disease

Gaucher's disease is part of some thirty family-genetic (inherited) diseases that are identified as lysosomal storage disorders (Rader, 2003). Persons that suffer from the disease lack the lysosomal enzyme Glucocerebrosidase which is necessary for breaking down lipids. Lipids build up in the liver and spleen and result in lung, bone, kidney problems and anemia (Goozner, 2000). Gaucher's disease is also very rare, affecting only about 20,000 people worldwide.[8]

The genetic defect causing Gaucher's disease was discovered in 1964, and the purified Glucocerebrosidase enzyme was first produced in 1974 (Goozner, 2000). The enzyme was initially purified from human placentas by Genzyme as the drug Ceredase and the process approved by the FDA in 1991 was very expensive. Genzyme continued to produce Ceredase from human placentas until 1995 when it licensed a recombinant version of the enzyme (Cerezyme) produced in Chinese Hamster Ovaries (CHO) (Goozner, 2000).9 Cerezyme was found to be a more effective treatment than Ceredase because of a slight genetic modification on the recombinant enzyme (Rader, 2003). Cerezyme is still the most effective treatment for

[7] Tobacco does not enter the food or feed supply and is either harvested before reaching maturity or tops are cut so that it does not flower and gene flow is almost entirely eliminated.
[8] This figure includes people that are taking treatment for Gaucher's disease and people that have not started the treatment yet (because the disease is in its initial stage) but are positively diagnosed.
[9] Recombinant proteins are proteins produced in the cells of genetically modified organisms.

Gaucher's disease and can be produced in larger quantities because it does not depend on the availability of human placentas. However, production is still very costly. A patient must take between 0.25 and 3 grams of Cerezyme every year at an average annual cost of $175,000 (Rader, 2003).

Cerezyme market

Genzyme is currently the only provider of a treatment for Gaucher's disease in the U.S. There is another product that is approved in Europe, Zavesca by Oxford Glycosciences Plc., but it is only used for patients with mild to moderate disease conditions (Rader, 2003). Genzyme's patent on Cerezyme expired in 2001 but its current manufacturing method is patented until 2011 and its composition until 2013 (Genzyme Corp., 2003). The market for Gaucher's disease treatment has always been a lucrative market and other companies have tried to develop more cost effective treatments, so far without success.[10] Thus, Genzyme maintains substantial market power. In the U.S., the price of Cerezyme has not changed during the last ten years and this is an additional indication of Genzyme's substantial market power.

The Model

An ex-ante analysis of potential benefits is conducted since the production of Glucocerebrosidase enzyme from transgenic tobacco is not currently being undertaken. The expected value of IPRs depends on the strategies of the innovating biotech firm (or of the firm that acquires the innovator's IPRs) and the incumbent. In this case Genzyme is assumed to be a perfect monopoly in the current market for Cerezyme. Further, the transgenic tobacco product is assumed to be of the same quality as Cerezyme. The successful developer of the patented transgenic production process may follow several potential strategies to compete with the

[10] Vevesca, an alternative Gauscher's disease treatment by Oxford Glycosciences went through all clinical trials and showed promising results but failed to gain approval in the U.S. and Europe because 11 percent of the patients developed nervous system complications.

existing monopoly, with no clearly preferred strategy identified in the literature. Some studies support the emergence of equilibria where firms choose between Bertrand (price-setting) and Cournot (quantity-setting) strategies (Allen, 1992; Qin and Stuart, 1997). Other studies support the emergence of a unique Cournot equilibrium (Kreps and Scheinkman, 1983; Tasnadi, 2006), and the emergence of a unique Stackelberg equilibrium (Saloner, 1987; Hamilton and Slutsky, 1990; Robson, 1990). The present study explores Cournot and Stackelberg strategies.[11]

Exact specifications of demand and marginal cost curve are needed in order to calculate the profit stream to the innovator, the change in incumbent's profits, and the consumer surplus generated from the biopharming application under each strategy. For simplicity, the Cerezyme market is characterized by linear marginal cost and demand functions derived from information on prices, quantities and elasticities.[12]

Under these assumptions the demand for Cerezyme in price dependent form is:

(1) $P = \mu - \lambda Q_d$

where P is the price of one unit of Cerezyme, Q_d is the quantity demanded and μ and λ are the intercept and slope terms, respectively. Thus the marginal revenue curve is:

(2) $MR = \mu - 2\lambda Q_d$

Similarly, a linear marginal cost curve of Cerezyme (in price dependent form) can be specified as:

(3) $P = \psi + \eta Q_S$

where Q_S is the quantity of Cerezyme produced and ψ and η are the intercept and slope terms, respectively.

[11] The Bertrand strategy is relatively trivial with the innovator charging a markup slightly less than the marginal cost advantage over the incumbent, and serving the whole market. The Bertrand strategy is also less profitable for both the innovator and the incumbent. Therefore, we focus on Cournot and Stackelberg strategies.

[12] These can be thought of as first-order approximations of the true underlying marginal cost and demand functions.

In the absence of information on the specific nature of the marginal cost shift associated with the innovation a parallel shift is usually employed, with a pivotal shift providing a distinct contrast in sensitivity analysis.[13]

The parallel outward marginal cost curve shift is represented as:

(4) $P = (\psi - k) + \eta Q_S$

where *k* is the size of the unit cost reduction expressed as cost savings for each gram of Glucocerebrosidase enzyme produced from transgenic tobacco compared to cell culture systems.

For comparison a pivotal marginal cost shift for the same unit cost reduction is represented as:

(5) $P = \psi + \eta_1 Q_S$

where $\eta_1 = \frac{{}^{c}P^0 - k - \psi}{{}^{c}Q^0}$ and ${}^{c}P^0$ and ${}^{c}Q^0$ are equilibrium price and quantity under perfect competition.

The incumbent as a monopolist charges a price mark-up above the marginal cost curve of:

(6) $\frac{P - MC}{P} = \frac{1}{PED}$

The price markup depends on the price elasticity of demand (PED) and the marginal cost curve of the monopolist. The point where the marginal cost curve and the marginal revenue curve meet is derived from (6) and it is used to obtain the slope and intercept parameters of the marginal cost curves in (4) and (5).

Cournot model

Under the Cournot model both incumbent and entrant choose the quantities produced in response to the quantity of the other firm. In equilibrium, both firms maximize profits based on

---

[13] Several studies including Alston et al. (1995) have found that generally, functional forms and elasticities are relatively unimportant in determining the size of total benefits compared with the nature of the supply shift. On the other hand, when determining the distribution of benefits, functional forms are relatively unimportant compared to the sizes of elasticities and the nature of the supply shift.

consistent beliefs about the other's output. Denote the incumbent's output level as q_1, the innovator's output level as q_2, and the aggregate output as $Q = q_1 + q_2$. Firm 1 has a cost function given by $c_1(q_1)$ and firm 2 has a cost function given by $c_2(q_2)$. The maximization problem of firm 1 is:

(7) $\max_{q1} \Pi_1(q_1, q_2) = p(q_1 + q_2)q_1 - c_1(q_1)$

Similarly, the maximization problem of firm 2 is:

(8) $\max_{q2} \Pi_2(q_1, q_2) = p(q_1 + q_2)q_2 - c_2(q_2)$

With consistent conjectures the solutions to the simultaneous equations from the first order conditions are:

(9) $q_1{*} = \dfrac{\lambda(\mu - 2\psi_1 + \psi_2) + \eta_2(\mu - \psi_1)}{\lambda(3\lambda + 2\eta_2 + 2\eta_1) + \eta_1\eta_2}$

and (10) $q_2{*} = \dfrac{\lambda(\mu - 2\psi_2 + \psi_1) + \eta_1(\mu - \psi_2)}{\lambda(3\lambda + 2\eta_2 + 2\eta_1) + \eta_1\eta_2}$

Based on equilibrium quantities, profits for each firm, the equilibrium market price, and the change in consumer surplus generated from the entrance of firm 2 can also be calculated.

Stackelberg model

In the Stackelberg model one firm moves first, and then, the other firm follows after observing the first firm's output. Again, the optimal output for the leader depends on consistent beliefs on how the follower responds. In the present study the incumbent is the follower and the innovating firm is the leader due to its entrance at a lower marginal cost.[14] To solve for equilibrium outputs we start from stage two and maximize the incumbent's profit as:

(11) $\max_{q1} \Pi_1(q_1, q_2) = p(q_1 + q_2)q_1 - c_1(q_1)$

[14] Harsayni and Selten (1988), and van Damme and Hurkens (1999) have shown that in a two-stage game the lowest cost firm emerges as the endogenous Stackelberg leader.

Equation (11) is similar to the Cournot condition derived above. Moving from the second stage to the first, the innovator now wants to choose its optimal level of output based on the incumbent's response. The profit maximization of the innovator in this case is:

(12) $\max_{q2} \Pi_2(q_1, q_2) = p(f_1(q_2) + q_2)q_2 - c_2(q_2)$

From the first order conditions of (11) and (12) the optimal output of the innovator and the incumbent are, respectively:

(13) $q_2{}^* = \dfrac{\lambda(\mu + \psi_1 - 2\psi_2) + \eta_1(\mu - \psi_2)}{\lambda(2\lambda + 2\eta_1 + 2\eta_2) + \eta_1\eta_2}$

and (14) $q_1{}^* = \dfrac{\mu - \lambda q_2{}^* - \psi_1}{2\lambda + \eta_1}$

Profits for each firm and changes in consumer surplus are again calculated based on the equilibrium quantities of the incumbent and innovator.

The value of IPRs

If the market is served by only one firm, acquisition of the innovator's IPRs by the incumbent allows it to obtain a patent on a more efficient manufacturing method and to retain a monopoly position in the market. As mentioned, such an acquisition likely violates Section 7 of the Clayton Act. The innovator's patent can, however, be purchased by another pharmaceutical firm not currently in the market and that is the case we consider. The effective patent life in the pharmaceutical industry is 12 years and that's the innovator's patent life assumed here.[15] Thus if the incumbent has operated for *t*-years in the market, the remaining patent life for the incumbent is 12 minus *t*-years. The value of the innovator's IPRs is calculated as the present value (PV) of the expected stream of profits during the effective patent life when it enters the market and

[15] Studies have found the effective patent life for pharmaceuticals to be 11-12 years on average (Grabowski and Vernon, 1994; Shulman et al., 1999).

competes with the incumbent. In this particular application, based on current patents, it is assumed that the incumbent's manufacturing method is patent protected for six more years and after that period it faces generic competition in the market.[16] Thus the present value (PV) of the expected stream of innovator's profits is the sum of profits during the first six years as a Cournot or Stackelberg competitor plus the profits from the sixth to the twelfth year when facing a competitive fringe after the incumbent's patent expires. After the twelfth year incumbent's profits are driven to zero because generics are produced using the incumbent's production method.[17] To simplify the analysis, it is assumed that when facing a competitive fringe in years 6 to 12 the innovator can drive out the competition in the market through limit pricing.[18]

During the limit price period, the expected PV of the innovator's profits is:

$$(15) \quad \Pi_g = \sum_{t=6}^{12} \frac{(k^{*c}\mathrm{Q}^0)}{(1+r)^t}$$

where k denotes the size of unit cost reduction, ${}^cQ^0$ denotes the quantity that would result if the market was competitive with the incumbent's technology, evaluated over the time generics may enter the market, $t = 6$, until the innovator's patent expires, $t = 12$, and r is the discount rate.[19]

The value of innovator's IPRs at time 0 is:

$$(16) \quad P_B = \sum_{t=0}^{6} \frac{\Pi_t}{(1+r)^t} + \Pi_g$$

where P_B is the price of innovator's IPRs, Π_t is the potential annual profit of the innovator under Cournot or Stackelberg in year t and, Π_g is the expected value of profits during the limit price period.

---

[16] The model is easily adjusted to accommodate a variety of cases with different effective patent lives.

[17] It is assumed that at this point generics are perfect substitutes for the original product.

[18] At the limit price, the innovator faces an elastic demand because it gains the whole market with a small price decrease.

[19] The discount rate is assumed to be five percent.

The PV of changes in consumer surplus under a duopoly at time 0 until the time incumbent's patent expires in year six is:

$$(17)\quad \Delta CS_d = \sum_{t=0}^{6} \frac{\{0.5[({\mu}-{}^{m}P^0)^{m}Q^0 - ({\mu}-{}^{m}P_i^1)^{m}Q_i^1]\}}{(1+r)^t}$$

where ${}^{m}Q^0$ and ${}^{m}P^0$ are the monopoly price and quantity with the incumbent's technology prior to innovator's entry, ${}^{m}P_i^1$ and ${}^{m}Q_i^1$ are the resulting equilibrium price and quantity after the innovator enters the market following a Cournot or Stackelberg strategy (i = Cournot, Stackelberg), t denotes each year from the time of the buyout until the incumbent's patent expires.

The PV of changes in consumer surplus, ΔCS_g from the time when generics may enter the market, $t = 6$, until the innovator's patent expires, $t = 12$, is:

$$(18)\quad \Delta CS_g = \sum_{t=6}^{12} \frac{\{[0.5({\mu}-{}^{c}P^0)^{c}Q^1 - 0.5({\mu}-{}^{m}P^1)^{m}Q^1]\}}{(1+r)^t}$$

where μ is the intercept of the demand curve, ${}^{c}P^0$ is the competitive price in the market with the incumbent's technology, ${}^{m}P^1$ is the monopoly price with the innovator's technology, ${}^{m}Q^1$ is the quantity supplied at that price.

It is important to note that the innovator and potential buyers are assumed to have the same information regarding market demand, firm marginal cost, and the time when generics may potentially enter the market. Otherwise, the price that potential buyers offer is different from the anticipated value of IPRs to the innovator. In order to highlight the role of the antitrust laws in enhancing competition, we also calculate profits and welfare changes if the incumbent was allowed to acquire the innovator's technology. Under this scenario, the PV of changes in consumer surplus at time 0 (when the incumbent acquires the innovator's IPRs) until the time incumbent's patent expires, $t = 6$, is now:

$$(19)\quad \Delta CS = \sum_{t=0}^{6} \frac{\{0.5\left[(\mu - {}^{m}\mathrm{P}^{0})\,{}^{m}\mathrm{Q}^{0} - (\mu - {}^{m}\mathrm{P}^{1})\,{}^{m}\mathrm{Q}^{1}\right]\}}{(1+r)^{t}}$$

where ${}^{m}P^{1}$ and ${}^{m}Q^{1}$ are the resulting monopoly price and quantity if the incumbent uses the innovator's technology, ${}^{m}Q^{0}$ and ${}^{m}P^{0}$ are the monopoly price and quantity with the incumbent's technology.

If the innovator accepts the offer, the PV at time 0 of nominal changes in incumbent's profits from using the transgenic production process is:

$$(20)\quad \Delta\Pi_{1} = \sum_{t=0}^{6} \frac{\{({}^{m}\mathrm{P}^{0} - {}^{m}\mathrm{P}^{1})\left[{}^{\mathrm{m}}\mathrm{Q}^{0} + 0.5({}^{m}\mathrm{Q}^{1} - {}^{m}\mathrm{Q}^{0})\right]\}_{t}}{(1+r)^{t}}$$

The real change in profits to the incumbent in this case is found by adding to its current expected profits (with the incumbent's technology) the change in monopoly profits using the innovator's technology (during the first six years), the profits during the limit price period from t = 6 to t = 12 in (15), and subtracting the price paid for IPRs to the innovator.

Protein Production Process, Unit Cost Reductions and Other Model Data

Cell culture systems vs. transgenic plants

A comparison of the unit cost of Glucocerebrosidase enzyme from CHO and the unit cost reduction from transgenic tobacco provides an example of the relative costs of cell culture and transgenic plants as systems for therapeutic protein production. Production of proteins from transgenic plants is similar to the production of proteins from the more established method of bioreactors using cell cultures. In both systems protein production can be divided into upstream and downstream processing. During upstream processing the proteins are produced in genetically engineered cells that express the desired proteins. Downstream processing then isolates and purifies the proteins.

Transgenic plants aim to replace cell cultures produced in bioreactors in the upstream process.[20] The economic advantages that transgenic plants can offer from the expression of proteins in their cells are lower capital requirements compared to bioreactors and also flexibility in supply. Increasing production capacity with cell culture systems requires a considerable fixed investment (more than $50 million for a bioreactor plant) and construction time (at least 5 years). Using transgenic plants for protein production is less expensive and production capacity can be extended by simply planting more acres. Glucocerebrosidase Enzyme was successfully produced in transgenic tobacco by CropTech (Blacksburg, VA). Crop Tech's estimates indicate that 1 mg of crude Glucocerebrosidase enzyme can be produced from 1g of fresh weight of tobacco leaf tissue (Cramer et al., 1996). Assuming a 40 percent recovery in order to achieve a pure product, and 40 metric tons of tobacco per acre (based on multiple cuttings), less than one acre of transgenic tobacco will be sufficient to meet Genzyme's current level of Glucocerebrosidase enzyme production. This low acreage suggests that the innovation will have little no impact on existing U.S. tobacco markets.

Unit cost reductions

Economic analysis of the production of therapeutic proteins from transgenic plants has been limited to date, largely because there is no drug of transgenic plant origin currently on the market. Consequently, there is no commercial scale processing of transgenic plants to generate accurate data on the economic benefits of biopharming. Nevertheless, estimates do exist on the production costs of proteins from transgenic plants (Kusnadi et al., 1997; Evangelista et al., 1998; Mison and Curling, 2000). Several important results can be synthesized from these studies. First, the cost savings with transgenic plant systems are almost all realized during the upstream

---

[20] Bioreactors are large containers made of stainless steel, glass or plastic which serve as a growth medium for the genetically engineered mammalian or bacterial cells in cell culture systems.

process, while techniques and costs during the downstream process are similar to those for protein produced in bio-reactors. Downstream processing includes filtration and purification using chromatography that account for 30 percent of the production costs (Millan et al., 2003). Second, the unit cost reduction in the upstream process is primarily due to capital cost savings. In transgenic plants, capital costs can be more than 95 percent lower than those in cell culture systems. Capital costs for cell culture systems can constitute 20 to 30 percent or more of protein production costs, but they depend on the size of the operation.

For output levels of 50 kg/year, unit cost reductions are estimated to range from 25 to 28 percent (Glacken, 2000) and 20 to 40 percent (Watler, 2002). Annual production of Glucocerebrosidase enzyme is 6 kg per year commercially. Thus, there is uncertainty about the exact unit cost reduction, but they can reasonably be assumed to range from a minimum of 10 percent up to a maximum of 40 percent, with a most likely value of 25 percent of the original production cost.

Market data

Estimates of the elasticity of supply of Cerezyme or similar products are not available in the literature. Nevertheless, considering that Genzyme is currently the only provider of a treatment for Gaucher's disease, information on prices and quantities over time may help to shed some light on the nature of the supply curve.[21] Cerezyme prices, quantities, and changes in quantity for five recent years are shown in table 1. The initial price (${}^{m}P^{0}$) of Cerezyme in the analysis is \$740 per 200 unit vial, since the price has not changed for the last decade. Because the quantity has been constantly increasing, taking an average for recent years would likely

[21] We use the elasticity of supply to derive the slope of the marginal cost curve.

underestimate the ex-ante benefits of the transgenic product.[22] Therefore, the initial quantity ($^{m}Q^{0}$) is set equal to the quantity in 2003. The direct price that Genzyme charges for Cerezyme has not changed from 1994 to 2004. The upward trend in the quantity of Cerezyme produced also suggests that Genzyme currently has the capacity to meet demand. The flexibility of supply suggests some excess capacity and that the supply of Cerezyme is elastic. For the study, the elasticity of supply is considered to be 2.0.

Demand, on the other hand, appears to be inelastic since a very limited number of people are carriers of the Gaucher's disease and only a few persons are diagnosed each year. Regular Cerezyme treatment for patients that are already diagnosed can successfully control and reverse severe conditions from the disease (spleen and liver enlargement, bone disease, anemia). However, microeconomic theory suggests that a monopolist maximizing its profits will never operate in the inelastic portion of the demand curve. Consequently, the elasticity of demand is considered to be -1.25.

Results

The estimated value of IPRs along with the changes in incumbent's profits ($\Delta\Pi$), and consumer surplus changes (ΔCS) are presented in table 2 for a minimum unit cost reduction of 10 percent, a most likely reduction of 25 percent, and a maximum reduction of 40 percent under both parallel and pivotal marginal cost shifts. An elasticity of demand of -1.25 and an elasticity of supply of 2.0 are used in these estimates. All results are reported as present values over a twelve year period.

[22] Our analysis on the 12 year period may still underestimate the value of IPRs because we are assuming constant number of cases of Gaucher's Disease.

The estimated value of IPRs with the most likely unit cost reduction is $1.72 billion if the innovator follows a Cournot strategy and $1.77 billion if it follows a Stackelberg strategy(T#3).[23] For a pivotal shift, the most likely unit cost reduction generates IPRs valued at $1.72 and $1.81 billion under Cournot and Stackelberg strategies, respectively. Consumers gain the most from the introduction of Glucocerebrosidase enzyme from transgenic tobacco in the market regardless of the entry strategy of the innovator. A 25 percent unit cost reduction with a parallel shift generates increases of $4.2 and $4.8 billion in consumer surplus under Cournot and Stackelberg strategies, respectively. Changes in consumer surplus are also slightly larger under a pivotal shift compared to a parallel shift for both strategies. As expected, the incumbent's profits decrease with the innovator's entry. Further, the innovator's IPRs value increases and incumbent's profits decrease with larger unit cost reductions under both types of marginal cost shifts.[24] In addition, the value of IPRs and the decrease in incumbent's profits are slightly larger under a pivotal shift compared to a parallel shift in marginal costs.

The impact of antitrust laws is also illustrated by reporting results in table 3 for the case when the incumbent is allowed to acquire the innovator's IPRs. Contrasting the results with those in table 2, two observations are worth noting. First, in both scenarios consumers are the main beneficiaries from the innovation. But the consumers gain significantly less if the incumbent acquires the innovator's IPRs. A $2.94 billion increase in consumer surplus is generated if the incumbent buys the innovator's IPRs. By comparison, gains in consumer surplus are $4.16 and $4.80 billion if the incumbent competes with the innovator using Cournot and Stackelberg strategies, respectively.

---

[23] If the innovator follows a Bertrand strategy, the incumbent exits the market and the estimated value of IPRs is $614 million. Thus, it is in the incumbent's and innovator's interest to follow either Cournot or Stackelberg strategies.

[24] The incumbent still makes profits but these profits are less than the profits when it was a monopoly in the Cerezyme market. Base monopoly profit for the incumbent is $2.98 billion.

Second, as expected, the incumbent's profits decrease by less when it buys the innovator's IPRs than when it faces an entrant and competes as a duopoly. If the incumbent acquires the innovators IPRs, with a 25 percent unit cost reduction and a parallel shift in the marginal cost curve, the reduction of the incumbent's profits is between $1.28 and $1.33 billion depending on whether the IPRs of the innovator are priced based on potential profits streams from Cournot or Stackelberg strategies. Incumbent's profit reductions are also lower as the unit cost reduction increases, as larger unit cost reductions translate into greater profits. These reductions compare favorably with the $1.64 and $2.11 billion reductions in profits associated with competing under Cournot and Stackelberg strategies, respectively. The choice between a parallel and a pivotal shift does not significantly impact the model results. Thus, the incumbent's best strategy would be to acquire the innovator's technology, since incumbent's profits decrease less and it can effectively extend the life of patented IPRs. However, as noted, Federal antitrust regulations are likely to block this strategy.

The sensitivity of the results to demand and supply elasticity parameter estimates are also considered by examining alternative demand elasticities between -1.001 and -1.5 and alternative supply elasticities between 1.5 and 2.5. The results are found to be generally robust to these ranges of supply and demand elasticities. However, the results do appear to be more sensitive to the precision of the supply elasticity estimates than the demand elasticity estimates. Holding the supply elasticity constant, incumbent's losses, profits to the innovator, and changes in consumer surplus increase (decrease) as demand becomes less (more) elastic under both Cournot and Stackelberg strategies and for both types of marginal cost shifts. With the elasticity of demand held constant, changes in the supply elasticity do not yield as uniform a set of trends across the various scenarios. Incumbent's losses increase (decrease) as supply becomes more (less) elastic, for both types of marginal cost shifts and under both entry strategies. However, the innovator's profits increase (decrease) with an increase (decrease) in supply elasticity under a parallel shift and decrease under a pivotal shift under Cournot strategy. Under Stackelberg strategy, profits to the innovator increase with increases in the supply elasticity for both types of marginal cost shifts. Consumers gain less as supply becomes more elastic when the innovator enters as a Cournot competitor under both parallel and pivotal marginal cost shift. On the other hand, when the innovator enters as a Stackelberg competitor changes in consumer surplus increase under a parallel shift, but decrease under a pivotal shift, as supply becomes more elastic.

Concluding Remarks

The economics of an innovation in an imperfectly competitive market are explored for the case of a small biotech firm successfully generating a lower cost process of production by biopharming. We estimate the value of the innovator's IPRs and the potential distribution of economic gains from entrance into a market with an incumbent monopolist. The analysis suggests the innovator's IPRs have a value of about $1.75 billion. Thus, potential profits are very large and capable of spurring significant investments in innovations for biopharming for therapeutic protein production. Yet, even with significant profits consumers remain the main beneficiaries from the lower cost process of producing Glucocerebrosidase enzyme from transgenic tobacco.

The FTC has established antitrust laws that prevent an incumbent from retaining market power by buying the IPRs of a potential rival. The present case demonstrates the effectiveness of such antitrust laws in increasing benefits to consumers from technical innovations. In the presence of antitrust regulations consumer surplus is almost 50 percent higher than when the incumbent is allowed to acquire the innovator's production process. Thus, regulations can play an important role in redistributing innovation benefits to a wider share of society, albeit while slightly blunting incentives for innovation.

References

Allen, B., 1992. Price and quantity competition in homogeneous markets. Economics Letters 38, 417– 422.

Alpert, B., 2004. Ripe for the picking- little biotech firms are catching the eye of big pharma juicy stocks? Baron's. April 19.

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

Cramer, C. L., Weissenborn, D. L., Oishi, K. K., Grabau, E. A., Bennett, S., Ponce, E., Grabowski, G. A., Radin, D. A., 1996. Bioproduction of human enzymes in transgenic tobacco. Annals of the New York Academy of Sciences 792, 62-72.

Evangelista, R. L., Kusnadi, A. R., Howard, J. A., Nikolov, Z. L., 1998. Process and economic evaluation of the extraction and purification of recombinant β-glucuronidase from transgenic corn. Biotechnology Progress 14, 607-614.

Gillis, J., 2002. Ernst & Young Release Global Biotech Report at BIO 2002. Pharmahorizons.com. Retrieved on May 5, 2005 from the World Wide Web: http://www.pharmahorizons.com/ErnstYoung.asp.

Genzyme Corporation., 2003. Annual Report.

Glacken, M. W., 2002. Plant transgenics vs. animal transgenics vs. CHO bioreactor culture: An objective comparison for monoclonal antibody production. Presentation in at the IBC's 8th Conference on Antibody Production and Downstream Processing, San Diego, California, February 8-12.

Goozner, M., 2000. The price isn't right. The American Prospect 11(20).

Grabowski, H., Vernon, H., 1996. Innovation and structural change in pharmaceuticals and biotechnology. Industrial and Corporate Change 3, 435-449.

Hamilton, J., Slutsky, S., 1990. Endogenous timing in duopoly games: Stackelberg or Cournot equilibria. Games and Economic Behavior 2, 29-46.

Harsanyi, J., Selten, R., 1988. A General Theory of Equilibrium Selection in Games. MIT Press Cambridge, Massachusetts.

Kreps, D., Scheinkman, J., 1983. Quantity precommitment and Bertrand competition yield Cournot outcomes. Bell Journal of Economics 14, 326-337.

Kusnadi, A., Nikolov, Z. L., Howard, J. A., 1997. Production of recombinant proteins in transgenic plants: Practical considerations. Biotechnology & Bioengineering 56, 473-484.

Marketing Research Bureau, Inc. Orange, Connecticut, USA., 2004. Personal Communication.

Millan, F. A., Mingo-Castel, A., Michael, M., Daniell, H., 2003. A chloroplast transgenic approach to hyper-express and purify human serum albumin, a protein highly susceptible to proteolytic degradation. Plant Biotechnology Journal 1, 71-79.

Mison, D., Curling, J., 2000. The industrial production costs of recombinant therapeutic proteins expressed in transgenic corn. BioPharm 13, 48-54.

Qin, C. Z., Stuart, C., 1997. Bertrand versus Cournot revisited. Economic Theory 10, 497–507.

Rader, R. A., 2003. Biopharma: Biopharmaceutical Products in the US Market, second ed. Biotechnology Information Institute, Rockville, Maryland.

Robson, A. J., 1990. Stackelberg and Marshall. American Economic Review 80, 69–82.

Saloner, G., 1987. Cournot Duopoly with two production periods. Journal of Economic Theory 42, 183–187.

Shulman, S.R., DiMasi, J.A., Kaitin, K.I., 1999. The impact of the Waxman-Hatch Act on new drugs and biologics approved 1984-1995. Journal of Biolaw and Business 4, 63-68.

Tasnádi, A., 2006. Price vs. quantity in oligopoly games. International Journal of Industrial Organization 24, 541-554.

van Damme, E., Hurkens, S., 1998. Endogenous Stackelberg leadership. Games and Economic Behavior 28, 105-129.

Walter, P. K., 2002. Processing design & economics for large scale monoclonal antibody manufacturing. Presentation at the IBC's 8th Conference Antibody Production and Downstream Processing, San Diego, California, February 8-12.

Zimm, A., 2007. Biotech firms become more tempting targets. The Philadelphia Inquirer. Retrieved January 30, 2007 from the World Wide Web: http://www.philly.com/mld/inquirer/business/16461995.htm.

Table 1. Cerezyme Price and Quantity Sold, 1999 -2003

Year	Sales of Cerezyme (millions)	Quantity of Cerezyme (number of 200 unit vials sold)	Percentage change in quantity	Price of Cerezyme ($/200 unit vial)
1999	479	647,297	-	740
2000	537	725,676	12	740
2001	570	770,270	6	740
2002	620	837,838	9	740
2003	734	991,892	18	740

Note: Prices represent the direct prices charged from the company for the 200 unit vial and sales of Cerezyme are the revenues of Genzyme for each year from charging the direct price.
Source: Marketing Research Bureau.

Table 2. Estimated Surplus Changes from Minimum, Most Likely and Maximum Expected Unit Cost Reduction under Cournot and Stackelberg (PV, in thousand U.S.D.)

Parallel Shift				
Unit cost reduction (%MC)		10	25	40
Cournot	Π Innovator	1,513,986	1,718,357	1,923,490
	ΔΠ Incumbent	(1,616,664)	(1,638,083)	(1,659,335)
	Δ CS	4,137,922	4,162,372	4,186,923
Stackelberg	Π Innovator	1,561,840	1,767,800	1,974,556
	ΔΠ Incumbent	(2,085,977)	(2,110,153)	(2,133,999)
	Δ CS	4,757,355	4,795,163	4,833,185
Pivotal Shift				
Cournot	Π Innovator	1,515,601	1,723,946	1,935,078
	ΔΠ Incumbent	(1,617,410)	(1,640,606)	(1,664,431)
	Δ CS	4,138,770	4,165,265	4,192,856
Stackelberg	Π Innovator	1,577,164	1,809,959	2,048,682
	ΔΠ Incumbent	(2,093,708)	(2,130,623)	(2,168,600)
	Δ CS	4,769,364	4,827,759	4,889,713

Note: Results in parenthesis indicate negative changes in profits.

Table 3. Estimated changes in Profits to Incumbent when Acquiring Innovator's IPRs (PV, in thousand U.S.D)

Parallel Shift			
Unit cost reduction (%MC)	10	25	40
ΔΠ Incumbent - Cournot	(1,338,421)	(1,277,896)	(1,216,276)
ΔΠ Incumbent – Stackelberg	(1,386,274)	(1,327,338)	(1,267,342)
Δ CS	2,890,855	2,944,534	2,999,141
Pivotal Shift			
ΔΠ Incumbent - Cournot	(1,356,215)	(1,322,652)	(1,288,306)
ΔΠ Incumbent – Stackelberg	(1,417,778)	(1,408,664)	(1,401,910)
Δ CS	2,882,764	2,924,950	2,968,920

Note: Results in parenthesis indicate negative changes in profits.

Essay 2

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

Introduction

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). Predictions of future drought and global warming forecast more severe droughts and climatic vulnerability (e.g. Wang 2006; McCarthy 2006). 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 (FAO, 1997).

Research on drought tolerance to date has been almost entirely conducted by the public sector through conventional breeding. However, plant breeders have begun to develop genetically modified (GM) varieties to address drought conditions in developing countries, especially in light of the emerging effects of climate change. As Dr. Jacques Diouf, Director-General, Food and Agricultural Organization of the United Nations (FAO) states "Most genetically modified (GM) crops being cultivated today were developed to be herbicide tolerant and resistant to pests. Development of GM crops with traits valuable for poor farmers, especially within the context of climate change - such as resistance to drought, extreme temperatures, soil acidity and salinity - is not yet a reality. I cannot sufficiently underline the need to also address the needs of resource poor farmers in rainfed areas and on marginal lands." (Ojanji, 2007). In fact, during the last few years the private sector has invested in developing transgenic drought resistant varieties for the rainfed and marginal areas. However the potential role of transgenic drought tolerance research in increasing the economic well-being of farmers in rainfed areas of developing countries is largely unknown. This paper develops a framework to document 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. Subsistence farmers in the rain-fed areas of these eight low-income countries rely substantially on incomes from production of main staple crops and yield stabilizing and yield increasing technologies may provide important means for enhancing the welfare of these vulnerable populations. Past research has focused almost exclusively on benefits generated by yield increases. The present study estimates the important additional 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 cereal drought tolerance are also explored in the ex-ante simulations. A benchmark investment from public sector conventional breeding drought research on maize, rice and wheat is also included in the analysis for comparison. A second important contribution of this paper is the generation of a spatial modeling approach based on agroecological zones and drought risk levels within the study countries that enables a more accurate characterization of drought research benefits and highlights common agroecological-drought risk zones across countries.

Risk benefits are found to be an important component of total transgenic drought tolerance research benefits particularly for Nigerian maize producers and Indian maize and rice producers in the semi-arid/arid high drought risk zone in the warm tropics and sub-tropics. Results also show that potential ex-ante benefits from transgenic drought resistant varieties on maize and wheat compare favorably with the benefits of conventional public breeding drought resistant research. In addition, benefits from private sector drought research are large when compared to benefits of other improved transgenic and non-transgenic varieties of maize, rice and wheat already released in the eight focus countries, especially when considering that the estimated benefits from drought tolerance research are limited to rainfed areas. Further, these benefits of transgenic drought tolerance research in maize and wheat largely complement the benefits from conventional breeding drought research for meeting future food needs and the challenges of climate change.

The rest of the paper is organized as follows. Section two provides a brief discussion on biotechnology and private sector investments 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 presented in section three. Section four lays out the model used to calculate the benefits of new variability reducing and yield enhancing 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 compares benefits with those expected from conventional drought tolerance breeding and benefit estimates from other transgenic and conventional maize and wheat research and concludes.

Biotechnology and Private Sector Investments to Develop Transgenic Drought Tolerant Varieties

Biotechnology has been the main source of agricultural growth during the last 15 years with a considerable number of herbicide and pest resistant genetically engineered varieties successfully generated and disseminated, and global area planted rapidly expanding from 4.2 million acres in 1996 to 222 million acres in 2005. Advances in molecular biology and genetic engineering have the potential to also reduce drought related losses in many crops and cropping systems (CGIAR, 2003; FAO, 2003; Doering, 2005). However, development of genetically engineered drought resistant varieties for developing countries has been slow in part due to constraints on market infrastructure and property rights protection that limit potential returns on investments (Hareau, Mills, and Norton, 2006). Despite these drawbacks, the private sector has been recently focusing on genetically modified drought tolerant varieties. For example, Monsanto spent $5 million on drought tolerant GM wheat research in 2004 (Sotckstad 2004), and obtained permission to test GM drought tolerant maize in open field trials in South Africa in 2007 with plans to move to commercialization as early as 2010 (African Center for Biosafey, 2007). Similarly the Victorian Government of Primary Industries was granted permission to conduct field trials on 30 GM drought wheat lines in Australia (Eyre, 2007).

Although information on productivity advantages of GM drought tolerant crops from the private sector is rare prior to their commercial releases, but the 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 when compared to traditional maize varieties (Garg et al., 2002). Monsanto's field trials on drought tolerant GM maize varieties in the U.S. indicated a 23 percent increase in maize yield compared to their non-GM counterparts

(Merret, 2007). Similar work on wheat shows 30 percent increases in fresh weight (e.g. Abebe et. al., 2003) and on rice (e.g. Quan et al., 2004) shows a 15 percent increase in photosynthesis efficiency.

Spatial Framework for Evaluation

Significant geographic variation in rainfall and other factors influencing drought implies the need for a spatially explicit evaluation framework to demarcate areas where research investments are likely to be fairly homogenous. The current framework starts with a total of sixteen agroecological zones (FAO/IIASA, 2000) and three drought risk zones (low, medium, and high).[25] The drought risk measure takes into account the point when the rainfall exceeds half potential evapotranspiration and the depletion of soil moisture in order to define the length of the growing season. The measure does not give a clear indication of the type of agricultural drought (e.g. early, mid or late in the growing season) that might occur, but variations in the length of growing season incorporate the effects of individual drought types (Pardey et al., 2006). Drought risk maps are then 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 preserve a satisfactory level of detail for the evaluation of drought risk. First, given that only a small percentage of cropped areas in the eight countries 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

[25] 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).

humid/sub-humid. Resulting zones provide relatively uniform environments within which to assess drought tolerance varietal development strategies.

Crop production and harvested areas are then estimated for agroecological-drought risk zones within each country. The drought risk map, the agroecological zones map, and the rain-fed cropped area map for India are provided as an example in figure 1, along with crop production and harvested area for rain-fed agroecological-drought risk zones in table 4.[26] Estimated production and harvested area data for the agroecological-drought risk zones of all eight countries are then reported in table 5. 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.

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

[26] 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.

research induced production 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.[27] 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:

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

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 the supply elasticity.[28]

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

---

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

[28] 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).

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 intellectual property rights 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;

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

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

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, benefits accrue from a reduction in yield variance 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:

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

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:

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

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:

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

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.[29] 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,

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

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 so 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 assume additive supply risk with linear demand and supply curves. Let the initial demand and supply be specified as:

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

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

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:

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

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 $(1-z)A\ \sigma_\alpha$. 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:

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

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 cost-reduction 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 to be the same as for 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 elasticity estimates for all crops and countries are summarized in table 6.

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 7 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 8). 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.

Technology Parameters

Mean yield increases are one of the two expected benefits of drought related research. Transgenic maize, rice, and wheat research efforts have generated have generated a few estimates of expected yield increases for drought tolerant varieties, even though drought resistance has not been a priority of transgenic research. 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) and a 23 percent yield increase over controlled non-transgenic maize reported by Monsanto (Merret, 2007). 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 drought resistant transgenic 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.[30] These expected mean yield increases are smaller than those actually achieved in the

[30] For all three crops the percentage increases in mean yields can be interpreted as the yields of the entire distribution will shift by these percentages.

experimental results to account for the fact that lower gains are usually found in farmers' fields from the adoption of new crop varieties.[31]

It is important to mention that the private sector has found it difficult to charge seed mark ups in developing countries. In addition, rice and wheat are self-pollinated pure line crops which make the collection of IPRs from the private sector even more difficult. However, evidence from private sector investments in maize and wheat suggests that the private sector possesses the technology to produce drought resistant seeds that needs to be purchased during each season. Significant private sector investment on drought transgenic rice is not yet a reality. For the purpose of this study we assume that the private sector is also able to collect the IPRs for such a technology and estimate ex-ante benefits under this 'best case' scenario for the private sector.[32]

Estimates are also available to guide parameterization on mean yield increases from drought resistance research in conventional breeding programs in different parts of the world. In fact CGIAR centers have already released for evaluation several drought tolerant lines of maize (CIMMYT), rice (IRRI, WARDA), and wheat (CIMMYT, ICARDA) (Bennet, 2003) and several drought tolerant varieties such as the drysdale semi-dwarf wheat in Australia and the ZM maize in Africa are already commercially available (Koechlin, 2004). Based on evidence from Ethiopia and South Africa, where the drought tolerant ZM maize varieties are commercially available and very successful (CIMMYT, 2004), a mean yield increase of 16 percent is assumed for conventional drought tolerant maize varieties in Africa. For Asia, adoption of drought tolerant maize varieties is assumed to lead to an 11 percent yield increase, since there has been less testing in the region. Yield increases of 10 percent and 12 percent are assumed for wheat and

[31] The expected mean yield increases may also be underestimated when considering that further technological improvements will be made so that today's experimental results might be lower than those expected when the drought-tolerant varieties are released.
[32] One way to collect IPRs would be to include terminator genes in rice but they have been subject to institutional debates. Thus the estimated potential benefits of drought transgenic rice may be optimistic.

rice, respectively, in both Asia and Africa. These estimates are lower than the yield increases in maize of up to 34 percent (CIMMYT, 2004), rice of up to 19 percent (Atlin, 2004) and in wheat up to 20-30 percent (CIMMYT, 2001) compared to traditional varieties in location-specific controlled experiments to reflect drops in yield gains on farmers' fields and the fact that some drought resistant varieties have already been developed.

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.

Using the Walker (1989) and Reardon et al. (1992) studies as benchmarks we assume conservative coefficients of yield variation of 0.5 and 0.3 for all three crops in high drought risk zones and low-medium drought risk zones, respectively. Specific data on potential yield variance reductions are not available. However, transgenic research is regarded as one of the most powerful avenues for stabilizing agricultural productivity in drought prone environments. Thus, we assume potential reductions of 25 and 15 percent in the coefficient of variation of yield from transgenic drought tolerant varieties for high and low-medium drought risk zones, respectively. Yield variance reductions from conventional breeding are assumed to be half the magnitude of those accruing from transgenic drought resistant research.

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 through private sector intellectual property rights. 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. One important concern on potential profits of transgenic crops in developing countries is the emergence of black markets for transgenic seeds that may lower potential profits to the private sector (e.g. Qaim and De Janvry 2003: Qaim and Basu 2007). The ex-ante analysis does not take into account the emergence of black markets in the eight countries suggesting that the actual profits may be smaller than the ones found in this study. Markets for transgenic seeds are already present in India, the Philippines, Bangladesh, Indonesia and (to a lesser extent) South Africa. However, markets for transgenic seed currently do not exist in Ethiopia, Nigeria and Kenya. Thus, the emergence of the black markets is expected to be more of a problem in the last three countries as they have weaker institutional foundations for transgenic seed markets and intellectual property rights protection.

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.

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 technology. 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 50 and 30 percent in high and low-medium drought risk zones, respectively. Given the low diffusion of transgenic varieties in low-income countries to date, 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). Lower adoption rates in the low-medium drought risk zones in part reflect lower expected variance reductions. A 50 percent adoption rate is assumed for public research drought resistant varieties across both high and low-medium agroecological drought risk zones to account for the fact that new varieties will compete with other improved varieties developed through conventional breeding.

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 9 as an example.[33] 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 by employing the expected adoption rates, mean yield increases, yield variance reductions and the other parameters discussed in the previous section.

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

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

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 benefit more from yield variance reductions than from mean yield increases. 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. 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. 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 10. 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 $626 million and $620 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 to $256 million and $313 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 $83 million and $105 million, respectively. Substantial benefits also accrue to producers and consumers in Nigeria, with total gains of $125 million. In general, maize producers and consumers in African countries benefit more than their counterparts in Asia from transgenic maize drought research. Benefits to the private sector from maize research are also substantial, especially in South Africa, Nigeria, and India with profits of $13 million, $12 million, and $9 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 the other countries. As rice is not a major crop among three of the countries 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 $74 million. In fact, estimated rice drought research benefits in Nigeria are larger than those in Indonesia and the Philippines. Transgenic rice drought tolerance research also generates sizeable profits to the private sector, most notably in India with private sector profits of $44 million.

Wheat drought research benefits are also substantial, especially for the producers and consumers in India with total gains of $43 million and $79 million, respectively, and producers in South Africa with benefits of $34 million. Private sector profits from transgenic drought tolerance research in wheat across all eight countries are relatively small at $21 million, especially when compared to the $178 million estimate of potential profits across the eight countries and three crops.

Ex-ante benefits from conventional breeding public sector research on drought tolerance are presented in table 11 as benchmark. The first notable finding is that private sector research has the potential to deliver more total benefits than public research in maize and wheat drought resistant research. In fact benefits to wheat producers and consumers are greater in all countries and agroecological-drought risk zones when compared to public sector research. However, public sector research has the potential to deliver more benefits to maize producers and consumers in the Philippines, Kenya and Ethiopia with total producer and consumer benefits of $24 million, $26 million and $27 million, respectively, compared to $22 million, $19 million and $23 million of potential benefits from transgenic research. Transgenic research in rice generates greater total benefits in India and the Philippines and producer and consumer benefits are smaller when compared to the public sector benefits at the country level. Nevertheless, benefits from transgenic research in high drought risk agroecological zones are greater for producers and consumers because of higher risk benefits in these zones.

Several key important estimates are likely to influence the magnitude and distribution of expected benefits in this analysis. As an example, table 12 shows the sensitivity of results to changes on variance reductions, mean yield increases, adoption rates, demand and supply elasticities, seed demand elasticity and seed costs for India.[34] Specifically, each parameter is increased and decreased by 50 percent compared to the initial estimates. The magnitude of changes in total expected benefits appears to be proportional with respect to changes in mean yields, yield variance reductions and adoption rates. The distribution of potential benefits from drought tolerance research mean yield increases among producers and consumers in each agroecological-drought risk zone depends on the elasticities of supply and demand employed,

[34] Sensitivity analysis is shown only for India, but the magnitude and distribution of benefits as a result of changes in the main parameters follows a similar pattern in the other seven countries.

with producers (consumers) experiencing the largest gains if supply is relatively less (more) elastic than demand. The magnitude of risk benefits from yield variance reductions, on the other hand, is sensitive to demand and supply elasticities. Specifically, producers and consumer benefits from yield variance reductions decrease with increases in the absolute value of the demand elasticity and the value of supply elasticity. Conversely, producer and consumer benefits increase substantially with decreases in the absolute value of demand elasticity and the value of supply elasticity. For example, total producer and consumer benefits from maize yield variance reductions in the low-medium and high drought risk zones of India are initially $16 million and $18 million, respectively, using a demand elasticity of -0.32 and a supply elasticity of 0.12. Simulations with an elasticity of supply of 0.18 (keeping the elasticity of demand at -0.32) generate total consumer risk benefits of $9 million and total producer risk benefits of $11 million. Similarly, a demand elasticity of -0.48 (keeping supply elasticity constant at 0.12) generates total consumer risk benefits of $10 million and total producer risk benefits of $7 million.

Private sector profits are particularly sensitive to the seed demand elasticity. 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 because of a lower seed mark up and a resulting drop in the cost of seed.

Conclusions

The estimated ex-ante transgenic drought tolerance research benefits for maize, rice, and wheat producers and consumers are substantial. Further, estimated annual benefits of $178 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 private sector involvement in transgenic drought tolerant research in major cereal crops. Producer and consumer benefits from transgenic drought tolerance research compare favorably with benefits from other ex-post studies on transgenic and non-transgenic agricultural technological improvements in the eight developing countries, as well as with potential benefits from conventional research on drought, especially in the agroecological zones under high drought risk. For example, ex-post studies have found annual benefits of $11.6 million for GM-maize in South Africa (Gomez-Barbero 2006), $291 million from improved maize varieties in Nigeria (Manyong et al., 2000) $515 million from improved wheat varieties in West and North Africa, $31 million in Sub-Saharan Africa and $1.8 billion in South Asia (CIMMYT, 1990). Ex-post studies on improved rice varieties have reported annual benefits of $601 million and $1.6 billion and $936 million in Bangladesh, Philippines and Indonesia, respectively (Hossain et al. 2003). The results of this paper indicate potential annual benefits of $200 million in South Africa and $137 million in Nigeria from transgenic drought tolerant maize, $98 million in the four countries in Sub-Saharan Africa from transgenic drought tolerant wheat, and $167 million, $323 million, $26 million, and $49 million from transgenic drought resistant varieties of rice in Bangladesh, India, Philippines, and Indonesia, respectively.

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 private investments. For example, the largest total benefits 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 40 percent of total benefits. These benefits are overlooked in almost all previous ex-ante analyses of research benefits. More refined parameterization of potential variance reductions and other parameters that underlie these benefits is an important area for further research.

References

Abebe, T., Guenzi, A.C., Martin, B., Cushman, J.C., 2003. Tolerance of mannitol-accumulating transgenic wheat to water stress and salinity. Plant Physiology 131, 1748-1755.

Abrar, S., 2003. Estimating supply response in the presence of technical inefficiency using the profit function: an application to Ethiopian agriculture. Working paper. University of Leicester, UK.

Acquaye, A.K.A., Traxler. G., 2005. Monopoly power, price discrimination, and access to biotechnology innovations. AgBioForum 8(2), 127-133.

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

Atlin, G. M, Laza, M., Amante, M., and H.R. Lafitte. 2004. Agronomic Performance of Tropical Aerobic, Irrigated, and Traditional Upland Rice Varieties in Three Hydrological Environments at IRRI. New directions for a diverse planet: Proceedings of the 4th International Crop Science Congress Brisbane, Australia, 26 Sep – 1 Oct 2004.

Bennet, J. 2003. Increased Water Productivity through Plant Breeding. In Kijne, J.W., Barker, R., and D. Molden, (eds.) Water Productivity in Agriculture: Limits and Opportunities for Improvement. CABI Publishing, Oxon, UK.

FAO. 1997. Report of the Study on CGIAR Research Priorities for Marginal Lands. Santiago, Chile. Retrieved on April 5, 2006 from the World Wide Web: http://www.fao.org/Wairdocs/TAC/X5784E/x5784e02.htm.

CGIAR, 2003. Applications of molecular biology and genomics to crop tolerance and abiotic stresses: a discussion document. Retrieved on Novemeber 5, 2006 from the World Wide Web: http://www.fao.org/WAIRDOCS/TAC/Y5198E/y5198e00.htm

CIMMYT, 2004. In quest for drought-tolerant varieties, CIMMYT sows first transgenic wheat field trials in Mexico". CIMMYT, Mexico.

CIMMYT. 2004. Drought Relief, Seed Relief in Sight. Retrieved on June 7, 2006 from the World Wide Web: http://www.cimmyt.cgiar.org/whatiscimmyt/recent_ar/D_Support/drought.htm.

Chand, R., Jha, D., 2001. Trade liberalisation, agricultural prices and social welfare. In: Acharya, S.S., Chaudhri, D.P., (Eds.), Indian Agricultural Policy at the Crossroads. Jaipur Rawat Publications, India, pp. 17–126.

Crawford, E.W., Oehmke, J.F., 2002. The sensitivity of returns of research calculations to supply elasticity. American Journal of Agricultural Economics 84, 366-69.

Doering, D.S., 2005. Public-private partnerships to develop and deliver drought tolerant crops to food-insecure farmers. CGIAR.

Edmeades, G.O., Bolaños, J., Lafitte, H.R., 1992. Progress in breeding for drought tolerance in maize. In: D. Wilkinson (Ed.), Proceedings of the 47th Annual Corn and Sorghum Research Conference. American Seed Trade Association (ASTA). Washington, DC.

Environmental News Service. 2006. Global warming could spread extreme drought. Environmental News Service, 5 October . Accessed on line at: http://www.ens-newswire.com/ens/oct2006/2006-10-05-01.asp.

FAO, 2003. Which road do we take? Harnessing genetic resources and making use of life sciences, a new contract for sustainable agriculture. Food and Agricultural Organization, Rome, Italy.

FAO/IIASA. 2000. Global agro-ecological zones. Food and Agricultural Organization (FAO), and Institute for Applied Systems Analysis (IIASA), Rome, Italy.

Falcon, W.P., Fowler, C., 2002. Carving up the commons – emergence of a new international regime for germplasm development and transfer. Food Policy 27, 197-122.

Falck-Zepeda, J.B., Traxler, G., Nelson, R.G., 2000. Surplus distribution from the introduction of a biotechnology innovation". American Journal of Agricultural Economics 82, 360–369.

FAOSTAT. 2006. FAO statistical databases. Retrieved on March 7, 2007 from the World Wide Web: www.fao.org.

Fischer, G., Velthuizen, H.V., Shah, M., Nachtergaele, F., 2002. Global agro-ecological assessment for agriculture in the 21st century: methodology and results. Research Report 02-02. Institute for Applied Systems Analysis (IIASA), Rome, Italy.

Friedman, J., Levinsohn, J., 2001. The distributional impacts of Indonesia's financial crisis on household welfare: a 'rapid response' methodology. Discussion Paper No. 482. School of Public Policy, The University of Michigan, Ann Arbor, Michigan.

Gabre-Madhin E., Barrett C.B., Dorosh. P., 2002. Technological change and price effects in agriculture: conceptual and comparative perspectives. International Food Policy Research Institute (IFPRI) Washington, DC.

Garg, A.K., Kim, J.K., Owens, T.G., Ranwala, A.P., Choi, Y.D., Kochian, L.V., Wu, R.J., 2002.

Trehalose accumulation in rice plants confers high tolerance levels to different abiotic stresses. Proceedings of the National Academy of Sciences, USA 99, 15898-15903.

Hareau, G., Norton, G.W., Mills, B.F., 2005. Potential benefits of transgenic rice in Asia: a general equilibrium approach. Quarterly Journal of International Agriculture 44, 229-46.

Heisey, P.W, Morris, M.L., 2006. Economic impact of water limited conditions on cereal grain production. In: Ribaut, J. (Ed.), Drought Adaptation in Cereals. The Haworth Press Inc., New York.

Jayne, T.S., Yamano, T., Weber, M., Tschirley, D., Benfica, R., Neven, D., Chapoto, A., Ballard, Z., 2001. Smallholder income and land distribution in Africa: implications for poverty reduction strategies. MSU International Department of Agricultural Economics Development Department of Economics Paper No. 24.

Khatun, F., Meisner, C.A., 2005. Success story of maize production in Bangladesh. Retrieved on October 23, 2006 from the World Wide Web: http://www.rwc.cgiar.org/RSCRTCC/2005/Sessions/6/FIROZA_Consort.pdf

Kiori, G., Gitu, K., 1992. Supply response in Kenya agriculture: a disaggregated approach. Ministry of Planning and National Development Technical Paper, Nairobi, Kenya, pp. 92-11.

Koechlin, F., 2004. Case study: transgenic drought and salt-tolerant plants. Workshop B2-Science and Technology Assessment – Case Studies. Blauen-Institut, Germany.

Kumar, P., Kumar, P., 2003. Food Production and Demand by State and Regions in India. Annual Report, 2002-03, NATP funded Project, Division of Agricultural Economics, IARI, New Delhi, India.

McCarthy, M. 2006. The century of drought. The Independent, 4 October. Retrieved on April 7, 2007 from the World Wide Web: http://www.independent.co.uk/environment/the-century-of-drought-418623.html.

Mangahas, M., Miralao, V. A., De los Reyes, R.P., 1974. Tenants, Lessees, Owners: Welfare Implications of Tenure Change. Institute of Philippine Culture, Ateneo de Manila University, Quezon City, The Philippines.

Morris, M.L., R. Tripp, Dankyi, A.A., 1999. Adoption and Impacts of Improved Maize Production Technology: A Case Study of the Ghana Grains Development Project. Economics Program Paper 99-01, CIMMYT, Mexico.

Nasol, R.L., 1971. Demand analysis for rice in Philippines. Journal of Agricultural Economics and Development 1(1), 1-13.

Newbery, D. M. G., Stiglitz. J.E., 1981. The Theory of Commodity Price Stabilization: A

Study in the Economics of Risk. Oxford: Clarendon Press.

Okoruwa, V.O., Lawal, B.O., Ajijola, S., 2005. Adoption of improved rice varieties among small-holder farmers in South-Western Nigeria. World Journal of Agricultural Sciences 1(1), 42-49.

Pardey, P. G., Beintema, N., Dehmer, S. and S. Wood. 2006. Agricultural Research: A growing Global Divide? IFPRI, Washington DC.

Pingali, P. L., Traxler. G., 2002. Changing locus of agricultural research: will the poor benefit from biotechnology and privatization trends? Food Policy 27, 223-238.

Qaim, M., De Janvry, A., 2003. Genetically modified crops, corporate pricing strategies, and farmers adoption: the case of Bt cotton in Argentina. American Journal of Agricultural Economics 85, 814–828.

Quan, R., Shang, M., Zhao, Y., Zhang, J. 2004. Engineering of enhanced glycine betaine synthesis improves drought tolerance in maize. Plant Biotechnology Journal 2, 477–486.

Reardon. T., Delgado. C., Matlon. P., 1992. Determinants and effects of income diversification amongst farm households in Burkina Faso. Journal of Development Studies 28, 264-297.

Revkin, A. C. 2005. Ocean warmth tied to African drought. The New York Time. Retrieved May 24,2005 from the World Wide Web: http://www.nytimes.com/2005/05/24/science/earth/24clim.html.

Rosegrant M. R, Paisner M. S., Meijer S., Witcover. J., 2002. Global Food Projections to 2020: Emerging Trends and Alternative Futures. International Food Policy Research Institute, Washington, D.C.

Sawahel, W., 2004. Egyptian scientists produce drought-tolerant GM wheat. SciDev. Net.

Traxler, G., Falck-Zepeda, J., Ortiz-Monasterio, R. J. I., Sayre. K., 1995. Production risks and the evolution of varietal technology. American Journal of Agricultural Economics 77, 1-7.

Tripp, R., 2002. Can the public sector meet the challenge of private research? Commentary on 'Falcon and Fowler' and 'Pingali and Traxler'. Food Policy 27, 239-246.

Zegeye, T., Taye, G., Tanner, D., Verkuijl, H., Agidie, A., Mwangi, W., 2001. Adoption of Improved Bread Wheat Varieties and Inorganic Fertilizer by Small-Scale Farmers in Yelmana Densa and Farta Districts of Northwestern Ethiopia. Ethiopia Agricultural Research Organization (EARO) and International Maize and Wheat mprovement Center (CIMMYT), Mexico.

Walker, T.S., 1989. Yield and household income variability in India's semi-arid tropics. In: Anderson, J.R., Hazell, P.B.R. (Eds.), Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries. Baltimore MD, John Hopkins University Press.

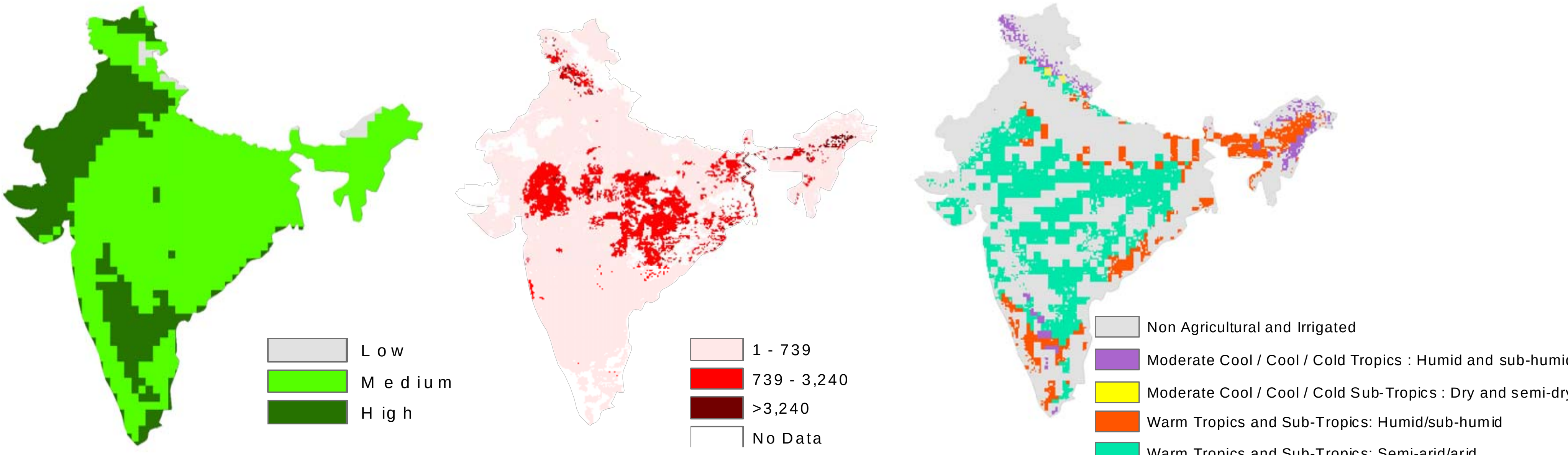
Wang, G. 2006. Agricultural drought in a future climate: results from 15 global climate models participating in the IPCC 4th assessment. Climate Dynamics 25, 739-753.

Warr, P., 2005. Food policy and poverty in Indonesia: a general equilibrium analysis. Australian Journal of Agricultural and Resource Economics 49, 429-451.

Wilhite, D. A. 2001. Creating a network of regional drought preparedness networks: A Call for action. Drought Network News 13, 1-5.

Figure 1.Drought Risk Agroecological Zones and Rainfed Production in India

Drought Risk* | Rainfed Cropped Area (ha/pixel) | Agroecological Zones



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

Source: Adapted from Fischer et al. 2002 | Source: IFPRI 2006 | Source: Wood et al. 2000

Table 4. 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 5. Maize, Rice, and Wheat Production Across the Rainfed Agroecological-Drought Risk Zones (thousand)

	Bangladesh		India		The Philippines		Indonesia		Kenya		Nigeria		Ethiopia		South Africa	
MAIZE																
	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 6. 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 7. 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
S. Africa	24.9	0.0	8.6

Table 8. 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 9. Potential Benefits from Transgenic Research Mean Yield Increases and Yield Variance Reductions in India (thousand U.S. dollars)

Agroecological-Drought Risk Zones		Maize			Rice			Wheat		
Benefits from mean yield increases										
		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	1,270	492	582	790	272	571	955	1,867	230
	Humid/sub-humid: High risk	510	198	173	1,178	406	508	633	1,237	150
	Dry and semi-arid: High risk	76	30	46	33	11	74	206	402	54
Warm Tropics and Sub-Tropics	Humid/sub-humid: Low-Med risk	4,163	1,611	1,257	21,132	7,287	17,588	6,388	12,485	1,745
	Humid/sub-humid: High risk	1,101	426	218	3,379	1,165	1,747	4,113	8,039	762
	Semi-arid/arid: Low-Med risk	9,671	3,743	4,622	18,553	6,398	19,680	14,338	28,024	5,426
	Semi-arid/arid: High risk	3,701	1,432	1,657	7,458	2,572	4,094	8,421	16,459	2,299
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	427	578	-	1,275	1,181	-	90	120	-
	Humid/sub-humid: High risk	1,028	1,031	-	3,558	4,504	-	272	353	-
	Dry and semi-arid: High risk	154	154	-	100	127	-	88	115	-
Warm Tropics and Sub-Tropics	Humid/sub-humid: Low-Med risk	1,398	1,896	-	34,111	31,602	-	600	806	-
	Humid/sub-humid: High risk	2,218	2,223	-	10,209	12,925	-	1,766	2,295	-
	Semi-arid/arid: Low-Med risk	3,249	4,405	-	29,948	27,746	-	1,348	1,808	-
	Semi-arid/arid: High risk	7,456	7,473	-	22,531	28,524	-	3,616	4,699	-
Sum of total benefits		36,422	25,692	8,555	154,255	124,720	44,262	42,834	78,709	10,666

Note: Elasticity of seed demand is -4.0.

Table 10. Potential Annual Benefits from Transgenic Research Mean Yield Increases and Yield Variance Reductions in All Eight Countries (thousand U.S. dollars)

		BGD	IND	PHI	IDO	KEN	NIG	ETH	SOA
Maize	Pr. Y	16	20,491	11,258	11,341	6,718	43,353	6,311	55,491
	Cs. Y	6	7,932	8,443	8,505	11,420	28,902	2,630	64,739
	Π	6	8,572	6,032	2,128	13,221	12,407	12,353	13,209
	Pr. RB	8	15,776	772	791	194	23,025	7,034	27,187
	Cs. RB	12	17,606	1,775	1,580	435	29,888	7,341	39,920
Rice	Pr. Y	32,664	52,522	11,633	19,628	104	23,630	-	10
	Cs. Y	11,264	18,111	6,017	15,266	121	27,568	-	11
	Π	15,062	44,319	4,895	8,110	148	16,106	-	5
	Pr. RB	47,741	101,632	1,065	1,623	133	8,956	-	9
	Cs. RB	60,860	106,482	2,163	4,092	197	13,611	-	14
Wheat	Pr. Y	2,699	35,053	-	-	1,900	1,870	6,721	26,689
	Cs. Y	1,227	68,513	-	-	1,330	1,309	4,704	18,682
	Π	427	10,683	-	-	764	147	6,272	2,812
	Pr. RB	2,506	7,692	-	-	792	601	1,601	7,194
	Cs. RB	2,836	10,082	-	-	1,026	790	2,228	10,573
	Total	177,332	525,468	54,053	73,063	38,501	232,163	57,195	266,544

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

Table 11. Potential Annual Benefits from Conventional Breeding Research Mean Yield Increases and Yield Variance Reductions in All Eight Countries (thousand U.S. dollars)

		BGD	IND	PHI	IDO	KEN	NIG	ETH	SOA
Maize	Pr. Y	18	20,002	12,076	6,203	9,458	40,131	10,992	54,765
	Cs. Y	7	7,760	9,057	4,652	16,079	26,754	4,580	63,892
	Pr. RB	5	12,017	721	660	141	17,600	5,479	19,586
	Cs. RB	6	13,414	2,639	1,317	317	22,858	5,739	28,565
Rice	Pr. Y	78,655	114,859	22,183	47,225	309	50,875	-	15
	Cs. Y	27,122	39,606	19,410	36,731	361	59,354	-	18
	Pr. RB	24,548	77,845	1,065	1,352	97	6,870	-	7
	Cs. RB	31,023	81,659	1,751	3,407	143	10,446	-	10
Wheat	Pr. Y	1,900	20,879	-	-	1,313	1,182	5,155	11,747
	Cs. Y	864	40,810	-	-	919	828	3,608	8,223
	Pr. RB	1,286	5,750	-	-	597	459	1,278	5,188
	Cs. RB	1,446	7,533	-	-	773	603	1,784	7,570
	Total	166,880	442,134	68,902	101,547	30,507	237,960	38,615	199,586

Table 12. India – Sensitivity Analysis on the Main Parameters (thousand U.S. dollars)

	Maize					*Rice*					*Wheat*				
	Pr. Y	Cs. Y	Π	Pr. RB	Cs. RB	Pr. Y	Cs. Y	Π	Pr. RB	Cs. RB	Pr. Y	Cs. Y	Π	Pr. RB	Cs. RB
Initial Estimates	*20,491*	*7,932*	*8,572*	*15,776*	*17,606*	*52,522*	*18,111*	*44,319*	*101,632*	*106,482*	*35,053*	*68,513*	*10,683*	*7,692*	*10,082*
Variance Red. + 50%	n.c.	n.c.	n.c.	22,607	25,754	n.c.	n.c.	n.c.	145,787	155,903	n.c.	n.c.	n.c.	11,194	14,708
Variance Red. - 50%	n.c.	n.c.	n.c.	8,260	9,021	n.c.	n.c.	n.c.	53,163	54,514	n.c.	n.c.	n.c.	3,962	5,179
Mean Yield +50%	31,620	12,240	n.c.	n.c.	n.c.	84,617	29,178	n.c.	n.c.	n.c.	53,944	105,436	n.c.	n.c.	n.c.
Mean Yield -50%	9,376	3,629	n.c.	n.c.	n.c.	20,426	7,043	n.c.	n.c.	n.c.	16,251	31,763	n.c.	n.c.	n.c.
Adoption + 50%	30,776	11,913	12,858	22,607	25,754	78,826	27,181	66,479	145,787	155,903	52,749	103,101	16,025	11,194	14,708
Adoption - 50%	10,233	3,961	4,286	8,260	9,021	26,247	9,051	22,160	53,163	54,514	17,470	34,147	5,342	3,962	5,179
El. Demand +50%	22,599	5,832	n.c.	7,361	9,846	57,437	13,204	n.c.	45,323	56,585	45,052	58,704	10,683	4,372	7,375
El. Demand -50%	16,012	12,396	n.c.	45,427	43,046	41,794	28,824	n.c.	296,438	269,820	21,043	82,259	10,683	14,059	14,607
El. Supply +50%	17,997	10,450	n.c.	9,282	11,772	46,570	24,088	n.c.	63,416	74,620	26,362	77,289	10,683	1,628	2,208
El. Supply -50%	23,789	4,604	n.c.	29,079	27,132	60,219	10,383	n.c.	174,418	156,103	52,293	51,105	10,683	37,120	42,695
Seed Demand El. + 50%	21,081	8,160	5,143	n.c.	n.c.	56,780	19,579	26,592	n.c.	n.c.	35,857	70,084	6,410	n.c.	n.c.
Seed Demand El. -50%	17,544	6,791	25,716	n.c.	n.c.	31,245	10,774	132,958	n.c.	n.c.	31,039	60,667	32,050	n.c.	n.c.

Note: n.c. = no change, Red. = Reduction and El.= Elasticty.

Essay 3

Ex-Ante Evaluation of Alternative Strategies to Increase the Stability of Cropping Systems in Eastern and Central Africa

Introduction

Agricultural producers in sub-Saharan Africa exist in a risk filled environment. Drought is widely recognized as a major source of production variability and a major source of risk in household income flows. Sub-Saharan Africa is seen as the core of the global drought and desertification problem (UNESCO, 2003). At least 60 percent of sub-Saharan Africa is vulnerable to drought and 30 percent is highly vulnerable (Benson and Clay, 1998). Predictions suggest that by 2050 some climates in the region will be 10 to 20 percent drier compared to the 1950-2000 averages (Kigotho, 2005). In addition, agricultural sources of fresh water are decreasing in both quality and quantity, causing farmers in irrigated areas to be increasingly categorized as 'partially' or 'poorly' irrigated (Toenniessen, 2003). On a global scale, estimates indicate that 65 percent of the poor households already live in drought-prone marginal areas where drought related crop losses may increase household exposure to poverty (FAO, 1997).

Few studies have documented the economic impact of drought related losses either worldwide or within countries, mainly due to data limitations. Nevertheless, estimated annual drought related losses of 25 million metric tons of rice and 20 million metric tons of maize in tropical areas, and 19 million metric tons of maize in non-temperate areas in the early 90's suggest that these losses are substantial (Doering, 2005). Global climate change is expected to increase the magnitude of drought related losses. Similarly, ex-post measures to reduce the effects of drought in poor countries are also costly. For example, the World Food Program spent $US 665 million in 2003, 85 percent distributed in sub-Saharan Africa and 15 percent in Asia, to protect vulnerable households in the face of drought and associated crop failure (World Food Program, 2003). Research on drought has to date mainly been conducted by the public sector through conventional breeding for drought-tolerant varieties. The African Maize Stress project, for example, has tested more than two thousand genotypes under drought conditions in Kenya (Bett et al., 2003; Hassan et al., 1998). Transgenic methods have been the major source for enhancing productivity in agriculture for the last two decades and recent studies suggest that there remains substantial room for genetic improvement to develop transgenic drought resistant varieties in semi-arid regions (CGIAR, 2003; FAO, 2003; Doering, 2005; Lobell et al., 2008). In fact multinational biotech companies such as Monsanto have already developed transgenic drought resistant varieties of maize and wheat, with open field trials of drought resistant maize currently under way in the U.S. and South Africa (African Center for Biosafey, 2007).

Farm households in developing nations are also exposed to a number of other sources of risk to agricultural income flows. Pests and crop diseases cause major yield losses which further increase the volatility of agricultural income (Hardaker, Huirne, Anderson, and Lien, 2004; Qaim and Zilberman, 2003). As agricultural production is an important source of income for many subsistence farmers in developing countries, agricultural technologies and policies that stabilize incomes and reduce production risk stand to reduce the vulnerability of smallholder households to poverty and increase welfare. However a framework for valuing the economic impact of production stabilizing technologies and policies for small scale producers is not currently available.

The purpose of this paper is to present a framework for measuring the benefits of agricultural research strategies that stabilize rural household incomes in the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) region. These ex-ante assessment tools will support the prioritization of technologies and policies that increase economic well-being by increasing and/or stabilizing agricultural incomes. The framework will focus on the ex-ante benefits of stabilizing agricultural incomes of farm households in the ASARECA region through new crop varieties that enhance productivity and reduce yield variability under drought conditions. However, the framework is easily adaptable to other 'yield-enhancing' and 'variability-reducing' technologies in agriculture, such as pest and disease resistant crop varieties. The framework will be applied to three major cereal crops; maize, sorghum and millet, in Kenya, Uganda and Ethiopia. The main objectives of this paper are:

- Specification of major drought risk zones in each of the administrative regions of Kenya, Uganda and Ethiopia and their intersection with the rainfed production areas of maize, millet and sorghum.
- Characterization of representative maize, millet, and sorghum producing households in rainfed areas of the major regions of Kenya, Uganda and Ethiopia.
- Ex-ante elicitation of research impacts on yields and yield variance.
- Economic modeling of mean-increasing and variance-reducing impacts of drought-resistant varieties on the well-being of representative households and on aggregate country level research benefits.
- Documentation of ex-ante private sector earnings from generation of transgenic drought-resistant varieties.

The rest of the paper is structured as follows. Section two describes the spatial framework and data used to characterize agricultural production and agricultural income risk in Kenya, Ethiopia and Uganda. The models used to measure the ex-ante economic impacts of mean yield increases and yield variance reductions are laid out in section three. Section four outlines the data used to obtain the ex-ante estimates. Results are presented in section five followed by concluding remarks in section six.

A Spatial Framework Characterizing Agricultural Production and Income Risk

Knowledge of drought risk and its spatial allocation can be a helpful tool for assessing the potential impact of drought related research programs. Several steps were taken in this study to identify and create relevant measures of drought exposure and their intersections with rainfed production in the major regions of Kenya, Ethiopia and Uganda. First agroecological zone maps were used to delineate maize, millet and sorghum production and planted area under rainfed conditions based on a 10km x 10km pixel resolution for each country.[35] Second, administrative maps were used for each country to extract production and planted area in each administrative region of each country. This administrative based division is necessary when using regional household data to estimate household level benefits which can then be aggregated and compared to market level benefits. Third, drought maps were overlaid on the rainfed production areas for each region within each country to create different drought risk level zones for each region.[36] Figure 2 illustrates the incidence and the level of drought risk along with the agroecological zones in the rainfed regions of Kenya. Most of the rainfed agricultural areas in Kenya are exposed to high drought risk.

Rainfed production results for each country are then allocated across country regions and the results for Kenya, Uganda, and Ethiopia (Amhara region) are presented in tables 13, 14 and

---

[35] Agroeological zones contain information on the rainfed regions and are simply used to extract the rainfed production and planted area for each country. Agroecological zones, drought risk maps, and production and planted area data for maize, millet and sorghum were kindly provided by IFPRI.

[36] Drought risk is derived by taking 30 years of actual rainfall and evapotranspiration data as input to a soil moisture model that accounts for both the depth and water holding properties of local soils (Fischer et al., 2002).

15, respectively.[37] Most of the maize, millet and sorghum production in Kenya takes place in the Rift Valley and Coastal region under high and medium drought risk conditions. A similar pattern is also found in Uganda where most of the maize, sorghum and millet production takes place in the Eastern region exposed to high and medium drought risk. Cropping patterns in the Amhara region of Ethiopia indicate that most of the production for each crop takes place under medium drought risk.

Measuring Economic Impacts of Mean Yield Increases and Yield Variance Reductions

The framework to measure ex-ante economic impacts of expected mean yield increases and expected yield variance reductions is laid out in this section.

Benefits of mean yield increases

The framework to evaluate the potential impact of technologies that increase mean yields is well developed (see Alston, Norton and Pardey, 1995). This partial equilibrium framework is based on consumer and producer surplus changes at the market level. In order to maintain consistency with benefit measures of research induced variance reductions, a more simple approach is applied in this study. The benefits of mean yield increases are measured as changes in producer and consumer income for each rainfed area with a uniform level of drought risk within the regions in each country. For example, rainfed crop production in the Central administrative region of Kenya takes place under medium and high drought risk. Thus, changes in producer and consumer income are estimated for the producers and consumers under the high drought risk production area of Central Kenya and for the producers and consumers under the medium drought risk areas in Central Kenya resulting in two different divisions: the medium drought risk and the high drought risk. This division is made in order to better specify and

[37] Household data was only available for the Amhara region of Ethiopia and it is the only region analyzed in this study.

capture the potential impact of drought resistant varieties which may have different responses under different drought risk levels. Similarly, production in the Central region of Uganda is divided among low, medium and high drought risk. Therefore analysis of the Central region for Uganda will be conducted separately for low, medium and high drought zones. Under this set up, the same level of drought risk in each region of Kenya, Uganda and Amhara region in Ethiopia are composed of a representative producer and a representative consumer. Drought resistant varieties result in yield increases which can also be translated into a unit cost reduction producer cost. Thus, the producer experiences a change in income from lower production costs but also a lower price from market induced price response. The consumer experiences a gain in income by consuming at a lower price.

The changes in producer and consumer income can be approximated as:

(1) $Pr.\ Y = KPQ_p - \Delta PQ_p$

(2) $Cs.\ Y = \Delta PQ_c$

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:

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

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. 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:

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

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..

The development of drought resistant varieties using transgenic methods will most likely arise from private sector investments with IPR protection on seed. Therefore, private sector profits are accounted for through a seed markup as in Falck-Zepeda et al. (2000). 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 seed for one hectare, C is the marginal cost of producing seed to plant one hectare and H is the area planted with the transgenic seed. 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, $P_m = C / (1 + \upsilon^{-1})$

where υ 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.

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 (1983). However, only Walker (1989) has attempted to quantify the benefits of yield variance reduction in a developing country context. He found very small risk benefits as a percentage of total producer income from completely eliminating the yield variance of one crop.

To measure the benefits of yield variance reductions we follow the Newberry-Stiglitz framework. Under this framework, the agroecological zones under the same drought risk level for each region in each country are considered to consist of a representative producer and consumer exposed to price and quantity variability at the market level.

The individual producer facing this risk has a Von-Newman Morgestern utility function of income *U(Y)* with:

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

where *R* is the coefficient of relative risk aversion. Producers are risk averse with respect to variations in incomes and changes in yield variations influence income variation. The reduction in yield variance will change the distribution of income from $\tilde{Y}_0$ with mean $\overline{Y_0}$ and coefficient of variation σ_{y0} to distribution $\tilde{Y}_1$ with mean $\overline{Y_1}$ and coefficient of variation σ_{y1}. The money value *B* for this reduction in income variation can be found by equating:

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

Expanding both sides of this equation using a Taylor series approximation, dividing both sides by $\overline{Y_0}\, U'(\overline{Y_0})$ and neglecting terms of order higher than σ_{y1} the equation reduces to:

(6) $$\frac{B}{\overline{Y_0}} = \frac{\Delta \overline{Y}}{\overline{Y_0}} - \frac{1}{2} R(\overline{Y_0}) \left\{ \sigma_{Y1}^2 \left(\frac{\overline{Y_1}}{\overline{Y_0}} \right)^2 - \sigma_{Y0}^2 \right\}$$

where $\Delta \overline{Y} = \overline{Y_1} - \overline{Y_0}$ and the first term on the right hand side is what Newbery and Stiglitz (1983) call transfer benefits while the second term is the risk benefit. If we focus solely on yield variance reductions, mean income $\overline{Y_0}$ does not change and producer risk benefits are measured as:

(7) $$\frac{B}{\overline{Y}_0} = \frac{1}{2} R \left\{ \sigma_{Y0}^2 - \sigma_{Y1}^2 \right\}$$

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

$$(8) \qquad \frac{B}{\overline{X}_0} = \frac{1}{2} R \left\{ \sigma^2_{p0} - \sigma^2_{p1} \right\}$$

where $\overline{X_0}$ is the mean consumer expenditure, σ^2_{p0} and σ^2_{p1} are the squared coefficient of variation of prices before and after the yield variance reduction, respectively, as price variability is the only pathway by which yield variability impacts consumers. Two simplifying assumptions on equations (7) and (8) are that the prices in other markets and producer and consumer income from other sources remain constant. From equations (7) and (8) it is clear that any empirical examination of risk benefits requires data on producer and consumer income, coefficients of variation of income, price, and quantity produced and a coefficient of relative risk aversion. Ideally one should start from each individual producer and consumer, and then aggregate them to model impacts on the whole market. In this study representative producers are generated based on household data for the agroecologial zones with the same level of drought risk within the administrative regions of each country.

Measures of reduction in the variance of income depend on the share of that crop in total producer income. Similarly, variance of total consumer expenditure depends on the share of the commodity in total expenditure. Thus, we need to account for the share of the income from each crop in total producer income and also the share of consumer expenditure on each crop in total consumer expenditure. These data are calculated from household surveys as described in more detail in the next section.

Specific assumptions are 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 are also sensitive to the specification of the source of risk (Newbery and Stiglitz, 1983). 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. We then assume additive supply risk with linear demand and supply curves. Demand and supply are thus specified as:

(9) $Q_d = \theta - \gamma P \quad (\gamma > 0)$

(10) $Q_s = \alpha + \beta P \quad (\beta > 0)$

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.

The yield variance reduction can be incorporated in the analysis as a reduction in the variability of supply (i. e. as a reduction in σ_α). Specifically, if the coefficient of yield variation is reduced by a fraction z and the adoption rate of the technology is Λ, then, the new supply variability is $(1-z)\Lambda\ \sigma_\alpha$.

Risk benefits

Newbery and Stiglitz (1983) provide a detailed discussion on the value appropriate value of the coefficient of relative risk aversion. Based on experimental evidence they assume a maximum value of 1.2 for producers' R and they use 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 for the market level estimates. Consumers are assumed to have an R equal to 1. Changes in the coefficient of variation of income can be found by comparing the difference on the variation of income with and without the yield variance reduction. Specifically, given demand and supply specifications the variance of the specific crop income is:

$$(11)\, Var(PQ) = Var\left[\left(\frac{\theta\beta+\gamma\alpha}{\gamma+\beta}\right)\left(\frac{\theta-\alpha}{\gamma+\beta}\right)\right] = E\left[\left\{\left(\frac{\theta\beta+\gamma\alpha}{\gamma+\beta}\right)\left(\frac{\theta-\alpha}{\gamma+\beta}\right)\right\}^2\right] - \left\{E\left(\frac{\theta\beta+\gamma\alpha}{\gamma+\beta}\right)\left(\frac{\theta-\alpha}{\gamma+\beta}\right)\right\}^2$$

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

$+$

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

Market level changes in the coefficient of variation in income are simulated by applying a reduction of (1-*z*) in the coefficient of variation for the zones with the same drought risk level within the regions of Kenya, Uganda and Amhara region in Ethiopia and adoption rates borrowed from other studies in these three countries. The shares of each crop on producer total income and consumer expenditure are based on household data as described in section three. Producer risk benefits can be calculated using equation (7). Consumers also experience changes in the variation of their expenditures from yield variance reductions through changes in the coefficient of variation of price. For the normal distribution, the variance of prices is:

$$(12) \qquad Var(P) = \left[\left(\frac{1}{\gamma+\beta}\right)^2 \sigma_\alpha^2\right]$$

Changes in the coefficient of prices are easily recovered from changes in yield variance and consumer risk benefits can be calculated from equation (8).

The economic impact of changes in agricultural productivity and risk on producing households

Expected changes in mean yields and yield variance can also be computed for representative producing household types (small, medium and large) by using the household data described in the next section and accounting for supply –shock-induced market-level price variance. These household-level welfare changes from mean yield increases and yield variance reductions are then aggregated as regional-level changes in economic well-being. The analysis starts with the mean (μ_{y0}) and the CV (σ_{y0}) of income for each household type. In order to find household level benefits we need to allocate the small, medium and large households in low, medium, and high drought risk zones of each administrative region in each country. Some administrative regions such as Nyanza in Kenya are exposed to the same level of drought. However, agricultural production in other administrative regions is exposed to more than one drought risk level. The household surveys described in the next section did not provide information on the location coordinates of the households. Therefore it is not possible to identify whether households are located in the low, medium or high drought risk zones within the administrative regions of each country. Thus, at the household level we cannot tell whether the production takes place in the low, medium or high drought risk zones for those regions with more than one drought risk level. Maize, sorghum and millet production and planted area data are available for each drought risk level within each administrative region of each country from the spatial analysis. This study assumes that the representative households are the same within each drought risk zone and uses regional representative households to characterize production in each drought risk zone within each region. However, all rainfed production in Kenya and the Amhara region in Ethiopia is exposed to medium and high drought risk levels. Similarly in

Uganda, most of the production takes place in the medium and high drought risk zones. The benefits from expected mean yield increases for each household type are then found as:

(13) $\Pr_{ij}.Y = \mathrm{P}_j \psi_j (\phi_j + 1) \zeta_{ij} - \Delta PQ_i$

(i = small, medium, large: j = low, medium and high drought risk)

where Pr. Y is the producer benefit from the crop, P_j is the new equilibrium price at the market level, ψ_j is the mean yield of the crop, ϕ_j is the expected mean yield increase, ζ_{ij} is the planted acreage, and ΔPQ_i is the change in the price level times the quantity produced before adopting the technology.

The risk benefits at the household level for each type of household are calculated as:

(14) $\Pr_{ij}.RB = 0.5 R Y_i s_{ijk} (\vartheta_{ij} \sigma_k^2 + \Delta \sigma_p^2)$

(i = small, medium, large: j = low, medium, high drought risk: k = maize, sorghum, millet)

where $\Pr_{ij}.RB$ is the producer risk benefits , R is the relative risk aversion coefficient, Y_i is the total household income, s_{ijk} is the share of the crop income on total income, ϑ_{ij} is the reduction in variation, σ_k^2 is the squared coefficient of variation of crop yield, and $\Delta\sigma_p^2$ is the change in the coefficient of variation of price at the market level.[38]

Aggregation to the regional-level is based on the weighted shares of maize, millet and sorghum planted acreage by small, medium and large households under each drought risk zone within each region. First to find the total planted area by household type for each drought risk zone, the total planted area of each drought risk zone within each administrative region is divided by the share of the total acreage planted from each household type across all surveyed households for that region. Then to find the number of households in each drought risk zone for

[38] It is assumed that the yield at the farm level is not correlated with the price at the market level.

each household type, the planted area from that household type is divided by the average planted area of the household type. Net benefits at the market level for small, medium and large producer households can then be found by aggregating benefits across adopting households and subtracting losses to non-adopters from the equilibrium price change at the market level.

Data Description

Several household surveys from Kenya, Uganda and Ethiopia are analyzed in this section and a literature review is conducted to obtain the parameter estimates for the simulation model. Both types of data and sources are described below.

Characterizing representative maize, millet and sorghum producing households based on household surveys

Agricultural production in Kenya, Ethiopia, Uganda, and the other seven countries of the ASARECA region occurs across a range of household types and the impacts of new drought resistant crop varieties will likely differ by household type. Existing household surveys for each country are analyzed to create three types (small, medium and large) of representative maize, millet, and sorghum producing households in rainfed regions agroecological-drought risk zones of Kenya, Uganda, and Amhara region in Ethiopia. The household types are characterized by the total farm acreage, income level, the share of maize, millet, and sorghum on the total acreage and total farm income, and the share of other major agricultural and non-agricultural income sources in total income.

First households were grouped according to their administrative regions. Then, households in each region were classified in three quantiles according to their total farm size and other summary statistics were generated for each quantile including the coefficient of variation (CV) of maize, sorghum and millet yield along and CV of total income. The most recent survey that contained information on the yields and prices of maize, millet and sorghum, as well as all income from all other sources was the Rural Household Survey for year 2000.[39] The means of these variables for 2000 are used in the model along with the CVs from the panel data (described in the next paragraph) to estimate the benefits of yield variance reductions for both representative households and at the market level. The means of the variables of interest during year 2000 for each representative household in each region are illustrated in tables 16 and 17. Results suggest that total household income increases with farm size in each region and maize is the most important source of crop income across all household quantiles. There are also differences in total household income across regions, where households in Nyanza have the smallest income and households in the Central region have the largest total income.

Panel data is necessary to derive the variation of yields, incomes and other parameters of interest for each household quantile. Four datasets were used to estimate the parameters needed for Kenya; The Rural Household Surveys of Kenya in 1997, 1998, 2000 and also the Rural Indicators Survey in 2002, all from Egerton University and the Tegemeo Institute/MSU. A total of 1540, 612, 1609 and 1768 households were interviewed in 1997, 1998, 2000 and 2002, respectively, of which 454 households were interviewed during all four years. The datasets of 1997, 1998 and 2000 provide detailed information on crop production, livestock production, livestock products, sales, prices, consumption, on-farm income, off-farm income and remittances, while, the 2002 survey includes only crop production, crop consumption and crop sales. The CVs of these variables of interest during the four years were computed for each household type in each of the five main regions as shown in table 18. Variation of crop yields at the household level is computed as kilograms harvested per amount of seed planted (instead of

[39] The Coastal region of Kenya did not have enough observations to compute the CVs of the main variables during the four years, however, it had enough observations in 2000, and it is still included in the analysis.

kg/ha) because the planted area was not reported for each crop individually. The CVs of yield were computed for each individual household and then averaged to create the representative households' CVs in yield for each farm type in each region. This method was also applied to obtain the CVs for the rest of the variables. CVs of total household income during the four years surveyed range between 0.38 and 0.64 and, except for small producers in the Nyanza region, are higher for small farms than medium and large farms, suggesting that poorer households face higher relative income fluctuations. The household data reveals that maize is the most important crop for Kenyan households with shares of 5.6 up to 23 percent in the total household income. Sorghum and millet income on the other hand contribute less with a minimum of 0.3 percent and a maximum of 7.0 percent in total income across all households surveyed. Maize yield CVs range between 0.5 and 0.7 and in most cases it is higher among small farms. Sorghum and millet yields also vary substantially.

No panel data is available for Uganda or Ethiopia. The 2005/06 National Household Survey from the Uganda Bureau of Statistics was used to create small, medium and large representative households and derive the parameters of interest for country regions. The survey covers a 12-month period from July 2004 until June 2005 and provides detailed information on crop production, consumption, sales, livestock production, livestock products, and each source of household income including gifts and remittances. The households were first divided according to the four main administrative regions of Uganda (Central, Eastern, Northern and Western) and then small, medium and large households were created based on the total farm acreage quantiles. A summary of the main variables for each representative Ugandan household in each region is presented in table 19. Results indicate that average total income increases with farm size. Maize income appears to be the most important source of crop income, while sorghum and millet income contribute with similar shares to total household income. On average, sorghum and millet in Uganda appear to contribute higher shares in total household income when compared to Kenya.

Household surveys of Ethiopia with all the information needed to create the variables of interest for this study were not readily available for all administrative regions. However, a complete household survey for 1999/2000 for the Amhara Region in Ethiopia was collected through collaboration of IFPRI, the International Livestock Research Institute (ILRI) and the Amhara National Regional Bureau of Agriculture and Natural Resources (ANRBANR). The household survey reports crop production, consumption, livestock production, livestock products, sales, prices, income sources, and remittances for each household participant. Similar to Kenya and Uganda, small, medium and large representative households were created based on total farm hectares for the Amhara region. Table 20 reports the main variables that are used in the model. Again, average total income increases with farm size. Small and medium sized households in the Amhara region earn more income from sorghum than maize, but, maize is still the most important crop planted in large households.

In the absence of panel datasets for Uganda and Ethiopia, we use the CVs of the Kenya panel for small, medium and large farms to account for the variability of maize, millet and sorghum yields, as well as total income variance.

Expected mean yield increases and yield variance reductions from public and private sector research

Public sector research has a long history of breeding for drought tolerant maize in drought prone areas. New classification and selection methods in maize breeding for drought tolerance have recently achieved promising results for the drought prone areas. Banziger et al.

(2006) report a 40 percent yield advantage for CIMMYT hybrid drought maize varieties at the 1-ton/ha yield level compared to private sector hybrids for the drought prone areas in Eastern and Southern Africa. In another field trial study, Betran et al. (2003) evaluated the performance of 17 inbred lines (9 of which were selected for drought) and the performance of hybrids in 12 tropical environments including severe drought risk and intermediate drought risk. Their results indicated that hybrids performed significantly better than inbreds with average grain yields of 1.14 Mg/ha compared to 0.15 Mg/ha for inbreds under severe drought stress. The hybrids also performed better in terms of stability showing almost half of the variation of the inbred lines selected for drought. Similarly, Seboksa, Nigussie and Bogale (2001) conducted field trials in Ethiopia concluding that it is possible to develop drought maize varieties with higher yield and greater yield stability across different drought prone environments. Other studies have also confirmed these results in drought prone environments of Mexico and Zimbabwe (Betran, Beck, Banziger, and Edmeades 2003; Worku et al. 2001; Tollenar and Lee 2002; Monneveux, Sanchez, Beck and Edmeades 2005). The new drought resistant varieties of maize, millet and sorghum developed through conventional breeding are expected to deliver yields that are at least as good as those of the current varieties during the good years and significantly better yields and less fluctuations in yields during bad years. Based on field trial estimates from the studies above and considering that farm level performance is generally lower than field trial performance we will assume 18, 13 and 10 percent increases in maize mean yields and variance reductions of 20, 15 and 10 percent in the high, medium, and low drought risk rainfed areas, respectively, in Kenya, Uganda, and Amhara region in Ethiopia. Maize, millet and sorghum breeding experts from CIMMYT and ECARSAM were also asked to state their opinion on potential mean yield increases and yield variance reductions for maize, millet and sorghum. They stated potential ranges of 10 percent to

50 percent with higher yields and variance reduction benefits in the higher drought risk rainfed areas.

Although information on productivity advantages of GM drought tolerant crops from the private sector is rare prior to their commercial releases, the 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 when compared to traditional maize varieties (Garg et al., 2002). Monsanto's field trials on drought tolerant GM maize varieties in the U.S. indicated a 23.3 percent increase in maize yield compared to their non-GM counterparts (Merret, 2007). In 2007 Monsanto obtained permission to test GM drought tolerant maize in open field trials in South Africa with hopes to achieve commercialization as early as 2010 (African Center for Biosafety, 2007). Private sector involvement in GM drought research suggests that higher yields and stability levels can be achieved via transgenic methods which are superior when compared to conventional breeding methods utilized mostly by public sector research. Thus, we assume that private sector GM drought resistant maize varieties achieve mean yield increases of 25, 20, and 15 percent in the high, medium, and low drought risk rainfed areas, respectively, in each of the three countries. In addition yield variance reductions of 25, 20, and 15 are assumed in the high, medium and low drought risk areas, respectively.

Sorghum and millet are also important staple crops in Africa where an estimated 300 million people in arid areas rely on them as a source of food (Reuters, 2006). They are known to perform well in drought prone areas, but there still are a lot of opportunities for improvement. Selection and breeding methods have recently resulted in very promising high yielding and yield stabilizing sorghum drought resistant varieties. Showemimo (2007) tested 20 different genotypes in 5 different locations in the savanna agroecological zone of Nigeria for three years and found average yields of 3.02 t/ha and square yield deviation of 0.07 across the 5 locations. These numbers compare very favorably with average current yield levels of less than 0.8 t/ha and high yield variability across regions and time. Haussmann et al. (2000) carried out a similar experiment in eight macro-environments in the semi-arid Makueni District of Kenya and found that hybrids outyielded their parents lines by an average of 54 percent and also showed the most favorable values in terms of stability. Other studies such as Reich and Atkins (1970), Jowett (1972) and Patanothai and Atkins (1974) have also found productivity and stability advantages of sorghum hybrids in drought prone environments. Mean yield increases of 18, 13, and 10 percent and yield variance reductions of 20, 15, and 10 percent in the high, medium, and low drought risk areas, respectively, are assumed in this study based on the findings and field trial data cited in the literature above.

Research on GM drought sorghum is still in its early stages but important steps have already been taken. For example, Bill and Melinda Gates' foundation donated $16.9 million to a project to develop GM drought sorghum and researches in Iowa State University claim that they are ahead of schedule and the materials look promising (Reuters, 2006). However, information on any results related to transgenic drought resistant sorghum or millet is available, thus, this study measures the ex-ante economics impacts of public sector research on sorghum and millet drought resistance.

Public sector research has indicated that significant improvements can also be achieved in millet yields under drought prone areas. For example, Yamoha et.al. (2002) showed that integrated crop residue management and crop residue plus fertilizer can result in 1.2 and 2 times better yields, compared to the control crops (no residue and no fertilizer) and yields under the integrated crop residue management were more stable than under the control. Omanya (2004) conducted on-farm yield trials for improved drought resistant millet varieties during the 2003 and 2004 seasons in Burkina Faso, Mali and Niger. The improved varieties showed 10 percent yield increases compared to the local varieties. Serraj et al. (2004) also point out that marker-assisted selection for drought tolerance in pearl millet have achieved significant improvements in yields. For the purpose of this study we will consider a 15 percent increase in mean yields in high drought risk rainfed areas, 12.5 percent increase in medium drought risk areas and 10 percent mean yield increases in low drought risk areas. In addition, variance reductions of 18, 14 and 10 percent are employed for the high, medium, and low drought risk areas, respectively, from public sector research on millet.

Adoption rates

Several studies report adoption rates of improved maize, millet and sorghum varieties in Africa. For example Maredia, Byerlee, and Pee (2000) estimated overall adoption rates of 37 percent in Africa for improved maize varieties with adoption rates of 70 percent in Kenya, 60 percent in Uganda, and 21 percent in Ethiopia and expected adoption rates of 18.8 percent for sorghum in Uganda, 37.5 percent in Kenya and 6 percent in Ethiopia.

Maize is the most important staple crops for the agricultural sector in Africa. Given that proposed varieties will be particularly beneficial for drought-prone areas, we assume adoption rates of 50 percent in the high drought risk zones, 40 percent in the medium drought risk zones and 30 percent in the low drought risk zones of Kenya for both transgenic maize drought resistant varieties from private sector research and drought varieties from public sector research. Studies on farmer adoption rates of sorghum and millet in Kenya show lower rates compared to maize. Thus, we assume adoption rates of 40, 30 and 20 percent for millet and sorghum in the high, medium and low drought risk areas, respectively.

Reported adoption rates of improved maize varieties in Uganda are slightly lower compared to Kenya. Therefore adoption rates of maize are assumed to be 40, 30 and 20 percent in the high, medium, and low drought risk areas, respectively. For sorghum and millet drought resistant varieties adoption rates of 20, 15, and 10 percent are employed in the high, drought, and low medium risk zones. Based on the reported adoption rates for maize in Ethiopia, a 25 percent adoption rate of drought tolerant maize varieties is assumed for the high drought risk zones of the Amhara region, a 20 percent adoption rate in the medium drought risk zones and a 15 percent adoption rate in the low drought risk zones. Finally, ex-ante adoption rates of 10, 8, and 6 percent are assumed for drought tolerant sorghum and millet in the high, medium and low drought risk zones of the Amhara region in Ethiopia.

Doss et al. (2003) analyzed twenty two micro level adoption studies in Kenya, Ethiopia and Uganda and found that farm size is not correlated with adoption of new improved varieties. Therefore, adoption rates of small, medium, and large farms are considered to be the same within the drought risk zones of the three countries. Adoption rates employed in this study are summarized in table 21.

Seed costs

Usually studies on seed cost assume a constant marginal cost per hectare. In this study we need estimates of the marginal production cost of transgenic drought resistant maize in Kenya, Ethiopia and Uganda. Juma (2008) reports maize seed costs of $US 8.0 per hectare in Kenya for the local varieties, while the cost of hybrid seed is $US 55.5. Private sector seed prices were reported to be $50 and $35.5 in 2001 for maize hybrid seeds from the private companies KSC and Pioneer, respectively (Nambiro, de Groote and Kosura 2001). Qaim and De Janvry (2003) assume a constant marginal cost of $25 per hectare for Bt cotton seed in Argentina and Khatun and Meisner (2005) find a cost of $25 per hectare in maize. Based on these studies we assume a constant marginal cost of $25 per hectare for transgenic drought resistant maize seed in Kenya, Ethiopia and Uganda.

Risk aversion coefficients at the household level

Studies have found that risk benefits are sensitive to the magnitude of the coefficient of risk aversion (Ligon and Schechter, 2004; Di Falco and Chavas, 2006; Chetty 2006; Isik, 2002). For example, Chavas and Holt (1996) estimate a coefficient of relative risk aversion of 6.07 for soybean and corn farmers in the U.S.. Di Falco and Chavas (2006) use a relative risk aversion coefficient of 2 and state that this is a moderate level of risk aversion for income. Brennan (2002) uses values of 2 and 3 for poor farmers. Other previous studies on developing countries have found values of R between 0 and 7 with a median around 1 (Arrow 1971: Binswager 1981). Barret et al. (2004) estimate a minimum R of 1.28 for the rice farmers in Madagascar. Chetty (2006) establishes a new method to estimate the coefficient of relative risk aversion and places an upper bound of < 2 for R. Based on this evidence we use a relative risk aversion coefficient of 1.2 for small, medium and large farmers.

Demand and supply elasticities

Supply and demand elasticities used in this study are borrowed from previous work in Ethiopia, Kenya and Uganda. A maize supply elasticity of 0.68 and a demand elasticity of -0.4 are estimated by Kiori and Gitu (1992) in Kenya and those are the values that we employ in this study. Sserunkuuma (2003) estimated maize supply elasticities in the range of 0.22 to 0.41 and demand elasticities in the range of -0.05 and -0.1 for Uganda. Therefore, we assume a supply elasticity of 0.31 and a demand elasticity of -0.075 for maize in Uganda. In his study in Ethiopia, Abrar (2002) found an elasticity of supply of 0.08 for maize. For Ethiopia we assume a maize demand elasticity of -0.4 and a supply elasticity of 0.08. For Kenya, Uganda and Ethiopia, in the absence of other country specific studies on supply and demand elasticites of sorghum and millet we employ an elasticity of supply of 0.35 and a demand elasticity of -0.30 as suggested in Gabre-Madhin et al. (2002) for crop supply and demand elasticities in developing countries. The demand and supply elasticities used in this study are summarized in table 22.

Results

Three types of results are presented in this section for the regions of Kenya, Uganda and the Amhara Region of Ethiopia. First, market level annual ex-ante public and private sector biotechnology research benefits from both mean yield increases and yield variance reductions are presented for the rainfed agroecological zones under each drought risk level in country regions. The market level results report changes in producer income (Pr. Y), changes in consumer income (Cs.Y), and private sector profits (Π), as well as producer risk benefits (Pr. RB) and consumer risk benefits (Cs. RB) for each drought risk level within each region in each country. Second, we present the benefits from mean yield increases and variance reductions at the household level for each household type in each region. Finally, we show aggregated market level benefits from mean yield increases and yield variance reductions based on household level aggregation. These benefits are then aggregated at the regional-level. All results are reported in $US dollars.

Total market level benefits for Kenya in table 23 suggest that public sector research on drought resistant maize varieties has the potential to generate significant benefits in the drought prone areas of Kenya, especially in the high drought risk regions. Producers and especially consumers in the Costal-High drought risk zone gain the most from maize public sector drought research. Consumers benefit more than producers from mean yield increases from maize drought research in Kenya. Producers and consumers in the Rift-Valley-Medium drought risk zone gain most of the benefits from millet drought research, while most of the benefits from public sorghum drought research are allocated to producers and consumers in the Coastal-High drought risk zone. Overall, consumers benefit slightly more than producers from sorghum and millet drought resistance research across all regions. Total annual benefits from public sector research in maize, sorghum and millet drought tolerance research across all regions in Kenya are $25 million, $1.8 million and $0.8 million, respectively.

Private sector benefits to maize consumers and producers are distributed similarly to public sector benefits. Overall, consumers gain more than producers from private sector research. One noticeable finding is that private sector drought research in maize generates greater total benefits for producers and consumers when compared to the public sector research, mainly because of higher potential mean yield increases and yield variance reductions. Consumers and producers benefit $26 million, with another $14 million of profits to the private sector from biotechnology research on maize drought tolerance.

Yield variance reduction benefits to Kenyan consumers and producers are estimated based on market level variance changes in income for public drought research in maize, millet and sorghum and private sector biotechnology research in maize. The results suggest that drought tolerance research benefits in maize mainly accrue yield through mean yield increases rather than yield stabilization. The share of risk benefits on total producer and consumer benefits from maize is 2 percent. Yield stabilization on millet and sorghum on the other hand contributes by 14 and 16 percent, respectively, on total producer and consumer benefits.

In addition to benefits from mean yield increases and yield variance reductions at the market level, we also present household level benefits for the representative producing households created in each region of Kenya from the household surveys, as well as aggregated regional-level benefits based on weighted acreage shares of representative households' production of maize, sorghum and millet. Benefits from public and private sector research on mean yield increases at the household level for small, medium and large maize, millet and sorghum producing households in Kenya are presented in table 24. Aggregated household level gains among the different producer types for the region are then shown in table 25.

As expected, benefits from public research mean yield increases at the household level are greater in maize compared to sorghum and millet since households plant larger areas with maize. Household benefits in the same region are on average greater for large farms, since they dedicate more acreage to each crop. Private sector research appears to deliver larger benefits than public sector research for each producer type.

Unlike in the market-level analysis, risk benefits from yield variance reduction at the household level are considerable in the high drought risk region of Kenya, especially for maize in the Eastern and the Rift Valley regions. Risk reduction benefits are considerable for millet and sorghum producers in Nyanza and Rift Valley regions. Although large and medium farms show greater risk benefits than small farms, the later still earn considerable benefits. Overall, producers benefit more from yield variance reductions with a share of 52 percent of total benefits at the household level. A similar distribution pattern is found for risk benefits from yield variance reductions for maize from private sector research. However, private sector research on drought generates greater benefits compared to public sector research benefits across all household types in Kenya.

Aggregated producer benefits in table 25 also reveal large benefits from mean yield increases. They are very similar in magnitude compared to producer benefits at the market level. In fact, in 8 out of 12 markets (four crops four each of the three countries) the difference in magnitude between aggregated producer benefits and producer income benefits at the market level is less than 2.3 percent, suggesting that aggregated producer benefits reconcile with their market-level counterparts. Small farms gain less than medium and large farms since the overall maize acreage of medium and large farms is greater. Most of the benefits from maize and sorghum drought research accrue to large farms in the Coastal-High Drought risk region, whereas millet drought research benefits accrue to medium sized farms in the Eastern-High drought risk region. Private sector research on drought resistant maize again results in larger aggregate benefits than public sector research for each producing household type. Aggregated producer risk benefits in maize are substantially greater than their market level counterparts.

Sorghum and millet producers' risk benefits from the household aggregation are on average larger compared to their market level counterparts. One reason for the large discrepancy between aggregated producer risk benefits and market-level risk benefits may arise from the assumption employed in this study postulating that yields on the household level are not correlated with market level prices. One way to test this assumption would be to collect large samples of panel data for each country and region and find the correlation coefficient between farm revenue, market price and farm yields.

The same ex-ante analysis is also conducted for Uganda in each of its four administrative regions: Central, Eastern, Northern and Western. Producer and consumer income changes from yield increases and yield stabilization at the market level for public sector research in maize, millet and sorghum are presented in table 26. Results suggest that the distribution of gains from sorghum and millet drought resistant varieties is almost equal between consumers and producers with only a slight advantage for consumers, however, consumers gain as much as four times more than producers from drought resistant maize varieties. Consumers in the Eastern-Medium drought risk region benefit the most from maize and millet drought research, while consumers and producers in the Northern-Medium drought risk region gain the most from sorghum drought research. Overall potential benefits of \$48.3 million, \$3.5 million and \$4.0 million are generated from public sector research in maize, sorghum and millet respectively.

A similar pattern of benefit distribution between producers and consumers emerges for the benefits from private sector research in maize. Overall, transgenic maize generates \$52.3 million for Uganda producers and consumers, which is slightly greater than public sector research benefits, plus an additional \$4 million generated as profits to the private sector.

Risk benefits from yield variance reductions at the market level are an important part of total benefits. In fact, maize producers gain significantly more from yield variance reductions compared to mean yield increases, and consumers' risk benefits are on average greater than those from mean yield increases. Sorghum and millet producers and consumer still earn considerable risk benefits, however, their benefits are smaller than income gains from mean yield increases.

Household level benefits from mean yield increases and yield variance reductions from drought research in maize, millet and sorghum in table 27 suggest that large producers in the Eastern-Medium drought risk region, in the Northern-High drought risk region and in the Western-Low drought risk region benefits the most from maize, sorghum and millet mean yield increases, respectively. In all cases large producers gain the most from drought research on mean yield increases followed by medium producers because they dedicate a larger share of their acreage to each crop compared to small and medium producers.

The lower panel of table 27 illustrates the representative households' risk benefits for each region from public and private research, respectively. In general, risk benefits increase with farm size, however, in a few instances risk benefits of small farms are larger than those of medium sized farms suggesting that the income for that crop is a relatively more important source of income for small farms. This is the case in the small millet and sorghum farms in the Northern-High drought risk region. Private sector drought resistant research on maize generates greater farm level benefits then public sector drought resistant research.

Next we present regional-level benefits from mean yield increases and yield variance based on aggregation from the household level in table 28. Regional-level benefits from maize mean yield increases among small, medium and large farms sum up to $2.17 million with $0.26 million to small farms, $0.56 million to medium farms and $1.35 million to large farms.. Drought resistant sorghum and millet generate aggregate level benefits of $0.95 million and $1.3 million of benefits across all three farm types from sorghum and millet, respectively, with large farmers gaining more benefits than small and medium farmers.

Aggregated risk benefits across all regions in Uganda are larger for maize compared to the benefits from mean yield increases with a total of $5.9 million from public research and an additional $7.2 million from private sector biotechnology drought research on maize. . Millet and sorghum risk benefits on the other hand are smaller than the benefits from mean yield increases with totals of $0.58 million and $0.44 million from public sector drought resistance research among sorghum and millet producers, respectively. Risk benefits comprise 65 percent of total research benefits among producers of maize, sorghum, and millet in Uganda.

As mentioned above, because of lack of data for all regions in Ethiopia, this study analyzes only the Amhara region. Most of the Amhara region area is exposed to medium drought risk with only a small fraction under high drought risk. Benefits from mean yield increases and yield variance reductions at the market level are presented in table 29.

These ex-ante estimates suggest that maize producers in the Amhara-Medium drought risk region gain substantial benefits from public sector research on mean yield increases and yield variance reductions in maize with a total of $4.9 million to consumers and $8.1 million to producers. Producers and consumers in the high drought risk zones of the Amhara region gain substantially less because of smaller planted maize areas. Sorghum and millet producers and consumers in the areas exposed to medium drought risk earn smaller benefits of $0.64 million and $0.17 million from public drought resistant research in sorghum and millet, respectively.

Private sector research on transgenic drought resistant maize is expected to generate more benefits than public research with $9.1 million gains to producers, $6.3 million to consumers and an additional $2.8 million profits to the private sector. However, public sector research generates more benefits to producers and consumers from mean yield increases compared to private sector research. Although potential mean yield increases from public sector research are smaller compared to their private sector counterparts, the seed mark up charged by the private sector increases production costs and results in lower overall gains in the maize zones. Risk benefits to producers and consumers are quite similar and the overall gains from yield variance reductions are greater than mean yield benefits, especially those from private sector research in transgenic maize. Most of the gains accrue to producers and consumers in the medium drought risk areas where most of the production takes place.

Producers' potential gains from mean yield increases and yield stabilization through public research in maize, millet and sorghum and maize drought research benefits from the private sector biotechnology are shown in table 30. Sorghum farmers are the ones that benefit the most from the technology. The reason is that those farmers specialize in sorghum production and plant larger areas of sorghum compared to the average planted area of maize and millet. Millet and sorghum producers in the high drought risk areas gain more on average than producers in medium drought risk areas. Farm level risk benefits from yield variance reductions through public research in maize, millet and sorghum as well as risk benefits from private sector research (lower panel of table 30) are smaller than the benefits from mean yield increases and suggest that most benefits accrue to large farms. As expected, farms located in the high drought risk areas of Amhara benefit more than the ones located in the medium drought risk areas because of higher potential yield variance reductions.

Aggregated producer benefits from mean yield increases and yield variance reductions are illustrated in table 31. Most of the gains accrue to large producers in the medium drought risk areas of Amhara. Public sector research in maize generates most benefits followed by sorghum drought research. This finding is similar to the finding at the market level suggesting that maize producers' net gains from private sector research are smaller compared to public sector research gains when accounting for the seed mark up paid by the adopting farmers. Millet small, medium and large producers in the high drought risk zones gain less compared to maize and sorghum producers because of a substantially smaller planted area in that region. Finally, potential ex-ante risk benefits are considerable are also considerable comprising 36 percent of total benefits of $10.4 million across all household from drought tolerance research on maize, sorghum and millet.

A set of sensitivity analysis is conducted on the most important parameters used in this study. The analysis is conducted only on the parameters used in the Eastern- Medium drought risk region and the Eastern-High drought risk region of Kenya. The reason is that the same methodology is applied to the regions of Uganda and Ethiopia, and Kenya's CV estimates for total income and yield variance were used for the regions of Uganda and Ethiopia in estimating the ex-ante benefits. More specifically, sensitivity analysis is conducted on the following parameters: mean yield increases, yield variance reductions, adoption rates, demand and supply elasticities. All these parameters are first increased then decreased by 50 percent from their initial values used in the estimation. For example, if the initial mean yield increase in maize was 20 percent, results are generated for mean yield increases of 30 percent (50 percent increase from the initial value) and 10 percent (50 percent decrease from the initial value).

Sensitivity analysis on adoption rates and mean yield increases at the market level are presented in table 32. Initial results are also reported in the same table. When initial adoption rates employed in the analysis are increased by 50 percent so that the new adoption rates in the high drought and medium risk areas of the Eastern region become 0.75 (from a 0.5 adoption rate) and 0.6 (from a 0.4 adoption rate), respectively, benefits increase by more than one third. Sensitivity analysis on supply and demand elasticities at the market level are not presented here for the case of mean yield increases at the market level, but, changes in demand and supply elasticity do not change the overall magnitude of benefits, only the distribution between consumers and producer. More specifically, a higher (lower) supply elasticity decreases (increases) producer benefits and a higher (lower) demand elasticity decreases (increases) consumer benefits.

A similar situation is found for the market benefits from private sector biotechnology research in drought resistant maize when mean yield increases and adoption rates are increased by 50 percent, where both benefits to producers and consumers as well as private sector profits (only in the case of adoption rate increases) increase by more than one third, as shown in table 33. Increases in the seed demand elasticity from -2 to -3 (by 50 percent), on the other hand, reduce profits to the private sector by half and increase benefits to producers and consumers.

The next set of sensitivity analysis is conducted on the main parameters used to estimate ex-ante risk benefits from yield variance reductions as shown in table 34. Risk benefits increase almost proportionally with further increases in yield variance reductions, but they are particularly sensitive to demand and supply specifications. For example when the supply elasticity is reduced by 50 percent, from 0.68 to 0.34, risk benefits to producers and consumers in the medium and high drought risk zones increase by more than five times on average. When demand becomes more elastic (by one half) producer and consumer risk benefits are smaller by less than a half on average compared to the initial risk benefits.

Finally sensitivity analyses are also conducted on adoption rates, mean yield increases and yield variance reductions at the household level. Regional level results of these sensitivity analysis based on household aggregation are reported in table 35 for both mean yield increases and yield variance reductions. Aggregated benefits from increases of 50 percent in both mean yields and adoption rates generate increases of roughly one half in the initial estimates suggesting that benefits increase/decrease proportionally with increases/decreases in mean yield increases and adoption rates. Similarly, increases by 50 percent in adoption rates and yield variance reductions generate aggregate risk benefits' increases of one half in the initial risk benefits at the aggregate level.

Conclusions

This study suggests that substantial ex-ante benefits can be generated from mean yield increases and yield variance reductions from public drought research on maize, millet and sorghum, as well as private sector drought research on maize, for producers in the rainfed areas of Kenya, Uganda and the Amhara region in Ethiopia. Furthermore, large potential profits exist for private sector and consumers in these developing countries. Kenyan total producers' and consumers' estimated ex-ante benefits from mean yields increases and yield variance reductions based on market level estimates suggest a total of $25 million, $1.8 million and $0.8 million of benefits from potential adoption of drought resistant maize, sorghum and millet, respectively, from public sector research on drought. Aggregated market level benefits to maize producers and consumers from transgenic drought tolerant maize mean yield increases and yield variance reduction aggregate to $30 million while the private sector profit estimates suggest potential profits of $14 million. An additional $7 million of potential profits to the private sector and $67 million benefits to producers and consumers are estimated in the maize areas of Uganda and Amhara region in Ethiopia. Furthermore, total ex-ante market level benefits add up to $62 million, $5 million and $4 million from public sector research on drought resistant maize, millet, and sorghum, respectively, from both mean yield increases and yield variance reductions. Risk benefits at the market level comprise 62 percent, 46 percent and 28 percent of these total drought research benefits in maize, millet and sorghum respectively.

Results based on the parameters employed in this study suggest that estimated ex-ante benefits from yield variance reductions can be an important part of drought related research with potential benefits similar to those from mean yield increases, especially in the medium and high drought risk areas where yields vary substantially from year to year. Household level results are aggregated to the market level to reconcile estimated market level benefits and provide important insights on potential research impacts across different household types. Results suggest that large producers in the rainfed regions of Kenya, Uganda and the Amhara region in Ethiopia benefit the most from drought research in maize, millet and sorghum farmers since they plant larger areas with these crops. However, small and medium maize, millet and sorghum also gain substantial benefits from both mean yield increases and yield variance reductions. These results have implications for equity objectives of agricultural research suggesting that policy makers should also seek alternative ways to increase the well-being of small farmers in the marginal areas. This type of framework can be easily adapted to other cases where policy makers seek market level as well as household type level benefits.

Overall, private sector maize drought research seems to be the most beneficial, however, transgenic drought resistant varieties have yet to pass regulatory approvals before they reach the seed markets in developing countries. Meanwhile, public sector research on drought resistance appears to be very promising for the farmers in the drought prone areas of the ASARECA region.

References

Abrar, S. 2003. "Estimating Supply Response in the Presence of Technical Inefficiency Using the Profit Function: An Application to Ethiopian Agriculture." Working paper. University of Leicester, UK.

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

Acquaye, A.K.A., and G. Traxler. 2005. "Monopoly Power, Price Discrimination, and Access to Biotechnology Innovations." AgBioForum 8: 127-133.

African Centre for Biosafety. 2007. Monsanto's Genetically Modified Drought Tolerant Maize In South Africa. Retrieved on September 17, 2007 from World Wide Web: http://www.biosafety-info.net/file_dir/30470589466cc4d9c5c2e.pdf.

Arrow, K. J. 1971. Essays in the Theory of Risk Bearing. North Holland Publishing CO.: Amsterdam.

Bänziger, M. Setimela, P. S. Hodson, D and V. Bindiganavile. 2006. "Breeding for improved abiotic stress tolerance in maize adapted to southern Africa." Agricultural Water Management 80(24): 212-224.

Barret, B. B., Moser, C. M., McHugh, O. V., and J. Barison. 2004. "Better Techonology, Better Plots, or Better Farmers?: Identifying Changes in Productivity and Risk Among Malagasy Rice Farmers." American Journal of Agricultural Economics 86(4): 869-888.

Benson, C. and E. Clay. 1998. "The Impact of Drought on Sub-Saharan African Economies." World Bank Technical Paper No. 401. 80 pp. The World Bank, Washington, D.C.

Betran, F. J., Beck D., Banziger, M. and G. O. Edmeades. 2003. "Genetic Analysis of Inbred And Hybrid Grain Yield under Stress and Nonstress Environments in Tropical Maize." Crop Science 43: 807-817.

Bett, C., De Groote, H., Diallo, A., Muasya, W., and K Njoroge. 2003. "Participatory Plant Breeding for Drought Resistant Maize Varieties in Eastern Kenya." 7th KARI Biennial Scientific Conference, 2000 - syngentafoundation.org

Binswager, H. P. 1981. "Attitudes towards Risk: Theoretical Implications of an Experiment in Rural India." The Economic Journal 91: 867-890.

Brennan, D. 2002. "Savings and Technology Choice for Risk Averse Farmers." Australian Journal of Agricultural and Resource Economics 46(4): 501-513.

FAO. 1997. "Report of the Study on CGIAR Research Priorities for Marginal Lands." Santiago, Chile. Retrieved on September 12, 2005 from World Wide Web: http://www.fao.org/Wairdocs/TAC/X5784E/x5784e02.htm.

CGIAR. 2003. "Applications of Molecular Biology and Genomics to Crop Tolerance and Abiotic Stresses. A Discussion Document."

Chavas, J. P. and M. T. Holt. 1996. "Economic Behavior Under Certainty: A Joint Analysis of Risk Preferences and Technology." The Review of Economics and Statistics 78(2): 329-335.

Chetty, R. 2006. "A New Method of Estimating Risk Aversion." American Economic Review 96: 1821-1835.

Chaudhuri, S., Jalan, J. and A. Suryahadi. 2001. "Assessing Household Vulnerability to Poverty From Cross-Sectional Data: A Methodology and Estimates from Indonesia." Unpublished Manuscript.

Doering, D. S. 2005. "Public-Private Partnerships to Develop and Deliver Drought-tolerant Crops to Food-Insecure Farmers." CGIAR.

Di Falco, S., and Chavas, J. 2006. "Crop Genetic Diversity, Farm Productivity and the Management of Environmental Risk in Rainfed Agriculture." European Review of Agricultural Economics 33: 289-314.

Doss, C. R., W. Mwangi, H. Verkuijl, and H. de Groote. 2003. "Adoption of Maize and Wheat Technologies in Eastern Africa: A Synthesis of the Findings of 22 Case Studies." CIMMYT Economics Working Paper 03-06. Mexico, D.F.: CIMMYT.

Falck-Zepeda, J.B., Traxler, G., Nelson, R.G., 2000. "Surplus Distribution from the Introduction of a Biotechnology Innovation." American Journal of Agricultural Economics 82: 360–369.

Falcon, W. P. and C. Fowler. 2002. "Carving up the Commons – Emergence of a new International Regime for Germplasm Development and Transfer." Food Policy 27: 197-122.

FAO. 2003. "Which Road Do We Take"? Harnessing Genetic Resources and Making Use of Life Sciences, a New Contract for Sustainable Agriculture."

FAO. 1995. "Sorghum and Millet in Human Nutrition." FAO Food and Nutrition Series, No. 27 ISBN 92-5-103381-1. Rome, Italy.

FAO/IIASA. 2000. "Global Agroecological Zoning."

Fischer, G., H. Velthuizen, H. V., Shah, M., and F. Nachtergaele. 2002. "Global Agro-ecological

Assessment for Agriculture in the 21st Century: Methodology and Results." RR-02-02. Institute for Applied Systems Analysis (IIASA).

Garg, A. K., Kim, J. K., Owens, T. G., Ranwala, A. P., Choi, Y. D., Kochian, L. V., and R. J. Wu. 2002. "Trehalose accumulation in rice plants confers high tolerance levels to different abiotic stresses." Proceedings of the National Academy of Sciences, USA 99, 15898-15903.

Gabre-Madhin E., Barrett C. B., and P. Dorosh. 2002. "Technological Change and Price Effects in Agriculture: Conceptual and Comparative Perspectives." International Food Policy Research Institute (IFPRI) Washington, DC.

Hardaker, J. B., Huirne, R. B. M., Anderson, J. R., and G. Lien. 2004. Coping with Risk in Agriculture. 2nd ed. CABI Publishing.

Hareau, G., Norton, G. W., and B. F. Mills. 2005. "Potential Benefits of Transgenic Asia: A General Equilibrium Approach." Quarterly Journal of International Agriculture 44: 229-46.

Hassan R. M., Njoroge K, Njore M, Otsyula R and Laboso A. 1998. Adoption Patterns and Performance of Improved Maize in Kenya. In: Hassan, RM. (ed.). Maize technology and transfer: aGIS application for research planning in Kenya. New York NY: CAB International.

Haussmann, B. I. G., Obilana, A. B., Ayiecho, P. O., Blum, A., Schipprack, W. and H. H. Geiger. 2000. "Yield and Yield Stability of Four Population Types of Grain Sorghum in a Semi-Arid Area of Kenya." Crop Science: 40:319-329.

Hyman, G., Fujisaka, S., Jones, P., Wood, S., de Vicente, C., and J. Dixon. 2007. " Strategic Approaches to Targeting Technology Generation: Assessing the Coincidence of Poverty and Drought-Prone Crop Production." IFPRI/CIAT/CIMMYT working paper.

Isik, M. 2002. "Resource Management under Production and Output Price Uncertainty: Implications for Environmental Policy." American Journal of Agricultural Economics 84: 557-571.

Jowett, D. 1972. "Yield Stability Parameters for Sorghum in East Africa." Crop Science 12:314-317.

Juma, J. 2008. "The Cost of Evading Costs." The African Executive. 09-16 April. Retrieved on April 17, 2008 from World Wide Web: http://www.africanexecutive.com/MODULES/MAGAZINE/ARTICLES.PHP?ARTICLE=856#.

Khatun, F., Meisner, C.A., 2005. Success story of maize production in Bangladesh. Retrieved on

October 26, 2006 from World Wide Web: http://www.rwc.cgiar.org/RSCRTCC/2005/Sessions/6/FIROZA_Consort.pdf

Kigotho, W. 2005. "Decades of Drought Predicted for Southern Africa." Retrieved on June 2, 2005 from World Wide Web: SciDev.Net.

Kiori, G. and K. Gitu. 1992. "Supply response in Kenya agriculture: a disaggregated approach." Ministry of Planning and National Development Technical Paper 92-11. Nairobi, Kenya.

Ligon, E., and L. Schechter. 2004. "Evaluating Different Approaches to Estimating Vulnerability." Working paper. University of California, Berkley.

Lobell, D. B., Burke, M. B, Tebaldi, C., Mastrandrea, M. D., Falcon, W. P. and R. L. Naylor. " Prioritizing Climate Change Adaptation Needs for Food Security in 2030". Crop Science 319: 607-610.

Maredia, M. K. Byerlee, D. and P. Pee. 2000. "Impacts of Food Crop Improvement Research: Evidence from sub-Saharan Africa." Food Policy 25: 531-559.

Merret, N. 2007. 'GM Food Industry Eyes Growth in the East'. Food Navigator. Retrieved on March 27, 2008 from World Wide Web: http://www.foodnavigator.com/news/printNewsBis.asp?id=74788.

Monneveux, P., Sanchez, C., Beck, D. and G. O. Edemeades. 2005. "Drought Tolerance Improvement in Tropical Maize Source Populations: Evidence of Progress." Crop Science 46: 180-191.

Moyo, S., Norton, G. W., Alwang, J., Rhinehart, I, and C. M. Deom. 2007. "Peanut Research and Poverty Reduction: Impacts of Variety Improvement to Control Peanut Viruses in Uganda." American Journal of Agricultural Economics 89(2): 448-460.

Muhammad L., K. Njoroge, C. Bett, W. Mwangi, H. Verkuijl and H. De Groote. 2003. The Seed Industry for Dryland Crops in Eastern Kenya. Mexico, D.F.: CIMMYT and Kenya Agricultural Research Institute (KARI).

Nambiro, E., de Groote, H., and W. O. Kosura. 2001. "Market Structure and Conduct of the Hybrid Maize Seed Industry: A Case Study of the Trans Nzonia District in Western Kenya." Seventh Eastern and Southern Africa Regional Maize Conference, 11th-15th February, pp.474-479.

Nyoro, J. K., Kirimi, L. and T. S. Jayne. 2003. "Competitiveness of Kenyan and Ugandan Maize Production: Challenges for the Future." Tegemo Institute of Agricultural Policy and Development. Working Paper 10.

Omanya, G. O. 2004. "Evaluation of Pearl Millet Resistant Varieties with Farmers in West

Africa." Paper presented in the Conference 'Rural Poverty Reduction through Research and Development', October 5-7, Berlin.

Patanothai A. and R.E Atkins. 1974. "Yield stability of single crosses and three-way hybrids of grain sorghum." Crop Science 14:287-290.

Pingali, P. L., and G. Traxler. 2002. "Changing Locus of Agricultural Research: will the Poor benefit from Biotechnology and Privatization Trends?." Food Policy 27: 223-238.

Qaim, M., and D. Zilberman. 2003. "Yield Effects of Genetically Modified Crops in Developing Countries." Science 299: 900-902.

Retuers. 2006. "GM Sorghum to Feed Africa's Starving." Retrieved on March 27, 2008 from World Wide Web: http://www.int.iol.co.za/index.php?click_id=68&art_id=vn20060331030908122C825789&set_id=.

Reich, V.H. and R.E. Atkins. 1970. "Yield stability of four population types of grain sorghum, *Sorghum bicolor* (L.) Moench, in different environments." Crop Science 10:511-517.

Seboska, G., Nigussie, M., and G. Bogale. 2001. "Stability of Drought Tolerant Maize Genotypes in the Drought Stresses Areas of Ethiopia", Seventh Eastern and South Africa Regional Maize Conference, 11-15 February, pp. 301-304.

Serraj, R., Hash, C.T., Yadav, R. S. and F. R. Bidinger. 2004. "Recent Advances in the Marker-Assisted Selection for Drought Tolerance in Pearl Millet." New directions for a diverse planet: Proceedings of the 4th International Crop Science Congress Brisbane, Australia, 26 Sep – 1 Oct 2004.

Showemimo, F.A. 2007. "Grain yield response and stability indices in sorghum (Sorghum bicolor (L.) Moench)." Communications in Biometry and Crop Science 2 (1): 68–73.

Sserunkuuma, D. 2002. "The Adoption of Improved Maize Varieties in Uganda." A Paper Prepared for the Symposium on Green Revolution in Asia and its Transferability in Africa held on December 8-10, in Tokyo, Japan.

Toenniessen, G. H., O'Toole, J. C., and J. DeVries. 2003. "Advances in Plant Biotechnology and its Adoption in Developing Countries." Current Opinion in Plant Biology 6: 191–198.

Tollenaar, M. and E. A. Lee. 2002. "Yield Potential, Yield Stability and Stress Tolerance in Maize." Field Crops Research 75: 161-169.

Tripp, R. 2002. "Can the Public Sector Meet the Challenge of Private Research? Commentary on 'Falcon and Fowler' and 'Pingali and Traxler'." Food Policy 27: 239-246.

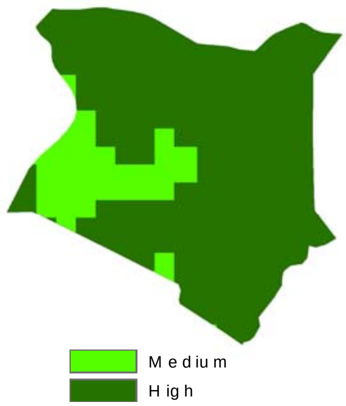
UNESCO. 2003. “Water for a Thirsty Planet.” A World of Science 1(2): 1-5.

Yamoah, C. F., Bationo, A., Shapiro, B. and S. Koala. 2002. “Trend and Stability Analyses in Millet Yields Treated with Fertilizer and Crop Residues in the Sahel.” Field Crops Research 75: 53-62.

World Food Program. 2003. Annual Performance Report.

Worku, M., Zelleke, H., Taye, G., Tolessa, B., Wolde, L. Abera, W., Guta, A. and H. Tuna. 2001. “Yield Stability of Maize (Zea mays L.) Genotypes Across Locations.” Seventh Eastern and South Africa Regional Maize Conference, 11-15 February, pp. 139-142.

Figure 2. Drought Risk and Agroecological Zones in Kenya



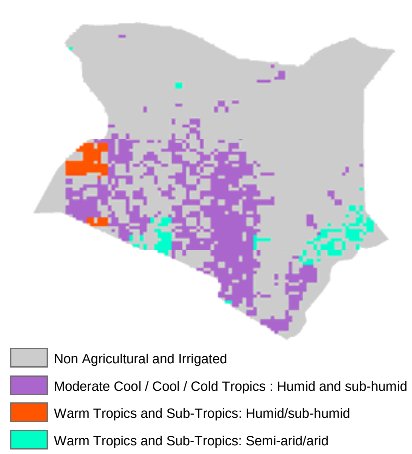


Table 13. Maize, Sorghum and Millet Production in Each Administrative region of Kenya

	Central	Eastern	Nyanza	Rift Valley	Northeastern	Western	Coastal
Maize Production under Rainfed Conditions (Mt)							
Medium Drought Risk	47,508	19,266	150,691	514,599	-	-	-
High Drought Risk	28,377	196,580	-	164,945	256	-	522,456
Sorghum Production under Rainfed Conditions (Mt)							
Medium Drought Risk	16,625	1,132	2,654	22,046	-	619	-
High Drought Risk	241	6,653	-	8,170	153	-	49,778
Millet Production under Rainfed Conditions (Mt)							
Medium Drought Risk	163	1,188	9,719	14,714	-	10,003	-
High Drought Risk	149	6,500	386	1,611	11	-	807

Table 14. Maize, Sorghum and Millet Production in each Administrative region of Uganda

	Central	Eastern	Northern	Western
Maize Production under Rainfed Conditions (Mt)				
Low Drought Risk	115,191	-	-	17,362
Medium Drought Risk	12,070	82,771	140,311	113,657
High Drought Risk	33,898	312,654	159,482	11,020
Sorghum Production under Rainfed Conditions (Mt)				
Low Drought Risk	7,603	5,737	-	16,396
Medium Drought Risk	2,453	26,686	158,794	47,970
High Drought Risk	3,705	54,704	9,468	-
Millet Production under Rainfed Conditions (Mt)				
		Moderate cool/cool/cold tropics		
Low Drought Risk	24,807	-	-	12,695
Medium Drought Risk	5,605	209,518	179,503	75,252
High Drought Risk	-	-	8,225	6,992

Table 15. Maize, Sorghum and Millet Production in Ethiopia – Amhara Region (Mt)

	Maize	Sorghum	Millet
Medium Drought Risk	1,504,189	645,901	95,492
High Drought Risk	16,292	57,310	147

Table 16. Characteristics of Maize, Sorghum and Millet Producing Households in Kenya in 2000 in the Central, Eastern and Nyanza Region

	Central (172 obs.)			Eastern (231 obs.)			Nyanza (263 obs.)		
	small	*med*	*large*	*small*	*med*	*large*	*small*	*med*	*large*
Avg. Maize Inc.	5,114	10,181	12,343	16,088	8,188	19,054	6,660	9,143	13,576
st.dev.	3,865	7,170	7,221	101,324	6,632	21,048	15,180	7,992	13,848
Avg. Sorghum Inc.	220	n.a.	326	815	871	3,137	1,335	1,972	3,232
st.dev.	n.a.	n.a.	n.a.	765	1,011	3,019	1,290	2,158	3,790
Avg. Millet Inc.	n.a.	n.a.	n.a.	554	692	2,198	885	1,829	1,782
st.dev.	n.a.	n.a.	n.a.	395	343	2,396	890	2,326	1,405
Avg. Maize Cons.	6,994	10,241	10,705	19,345	10,625	16,349	9,949	12,007	13,292
st.dev.	4,018	4,964	5,071	101,850	6,116	13,916	14,643	5,852	7,468
Avg. Sorghum Cons.	228	167	247	455	518	1,093	1,903	2,300	3,190
st.dev.	268	183	300	735	531	1,575	3,229	3,269	3,117
Avg. Millet Cons.	233	167	243	364	347	639	1,361	1,554	1,713
st.dev.	271	183	307	663	302	985	3,222	2,769	2,056
Avg. TOTAL Inc.	123,993	259,118	351,997	166,468	198,651	342,804	56,157	124,611	158,365
st.dev.	77,151	225,358	240,406	169,330	153,602	314,038	65,657	266,924	203,376
Avg. Maize inc. % of TOT. INC.	4.56	6.15	5.17	5.25	7.33	9.36	13.96	16.68	11.46
st.dev.	3.16	5.50	4.20	10.29	8.33	9.74	13.49	15.84	9.23
Avg. Sorghum inc. % of TOT. INC.	0.17	n.a.	0.28	0.82	1.10	2.24	6.08	6.46	5.00
st.dev.	n.a.	n.a.	n.a.	0.66	1.54	2.24	9.40	9.38	6.73
Avg. Millet inc. % of TOT. INC.	n.a.	n.a.	n.a.	0.48	0.36	0.60	1.64	1.49	1.53
st.dev.	n.a.	n.a.	n.a.	0.21	0.11	0.48	2.40	2.09	1.28
Avg. Maize Cons. % of TOT. INC.	7.69	6.59	4.33	10.01	9.38	9.54	52.40	32.64	16.66
st.dev.	8.45	6.55	2.99	15.08	8.69	9.16	114.24	40.91	13.66
Avg. Millet Cons. % of TOT. INC.	0.59	0.08	0.09	0.51	0.20	0.27	10.62	5.58	3.38
st.dev.	1.95	0.09	0.14	1.49	0.17	0.38	29.84	13.14	6.79
Avg. Sorghum Cons. % of TOT. INC.	0.57	0.08	0.09	0.60	0.52	0.83	13.40	9.23	6.04
st.dev.	1.92	0.09	0.14	1.45	0.76	1.51	31.48	15.15	7.84
Avg. Maize Yield (kg/kgseed)	79.15	73.04	80.21	70.33	63.70	47.13	65.28	47.63	56.82
st.dev.	51.40	46.87	76.95	74.17	49.53	42.98	154.98	45.49	52.89
Avg. Sorghum Yield (kg/kgseed)	2.00	n.a.	40.00	120.00	35.26	56.75	36.55	46.02	57.70
st.dev.	n.a.	n.a.	n.a.	135.65	30.33	74.98	41.23	70.50	70.60
Avg. Millet Yield (kg/kgseed)	n.a.	n.a.	n.a.	21.50	18.94	49.64	18.41	21.29	20.41
st.dev.	n.a.	n.a.	n.a.	5.74	9.57	44.13	17.02	16.26	14.62
Avg. Maize Price (KSH/kg)	14.45	16.32	13.00	13.87	12.98	11.83	12.82	12.64	13.26
st.dev.	2.54	10.54	2.98	4.25	3.83	2.64	2.92	3.21	2.78
Avg. Sorghum Price (KSH/kg)	27.03	n.a.	n.a.	n.a.	7.20	6.83	11.01	15.37	11.19
st.dev.	n.a.	n.a.	n.a.	n.a.	n.a.	3.04	3.55	10.08	3.15
Avg. Millet Price (KSH/kg)	n.a.	n.a.	n.a.	n.a.	22.22	32.50	19.71	21.55	19.72
st.dev.	n.a.	n.a.	n.a.	n.a.	n.a.	24.75	6.73	5.88	6.76

Notes: KSH- Kenyan Shillings (1 US dollar = 74 KSH)

Table 17. Characteristics of Maize, Sorghum and Millet Producing Households in Kenya in 2000 in the Rift Valley, Western and Coastal Region

	Rift Valley (378 obs.)			Western (284 obs.)			Coastal (87 obs.)		
	small	*med*	*large*	*small*	*med*	*large*	*small*	*med*	*large*
Avg. Maize Inc.	8,767	15,405	62,661	5,653	15,814	62,569	3,549	5,377	55,130
st.dev.	7,565	12,712	130,303	4,173	17,672	173,595	2,762	3,460	100,438
Avg. Sorghum Inc.	308	713	1,149	1,273	1,039	2,000	979	530	343
st.dev.	289	824	1,411	1,011	1,136	1,806	n.a.	173	551
Avg. Millet Inc.	590	1,206	2,269	982	1,616	4,736	n.a.	n.a.	67
st.dev.	451	1,942	2,920	878	1,830	8,459	n.a.	n.a.	68
Avg. Maize Cons.	9,750	10,830	20,522	8,909	14,229	26,288	11,159	16,629	57,601
st.dev.	6,993	6,656	18,872	4,211	7,555	28,655	9,307	10,078	89,911
Avg. Sorghum Cons.	321	466	735	969	714	1,285	468	493	303
st.dev.	243	568	1,040	920	999	1,548	500	255	389
Avg. Millet Cons.	436	716	1,327	661	826	2,066	404	474	316
st.dev.	378	1,468	1,710	781	1,119	3,320	494	311	423
Avg. TOTAL Inc.	94,108	121,106	304,292	70,934	144,613	276,707	101,513	89,354	230,780
st.dev.	78,795	105,536	336,108	67,873	104,707	260,927	82,053	64,818	188,539
Avg. Maize inc. % of TOT. INC.	15.31	18.79	21.50	12.75	13.41	18.84	5.03	8.44	24.91
st.dev.	14.69	17.74	18.53	12.31	11.92	18.91	4.00	8.19	25.23
Avg. Sorghum inc. % of TOT. INC.	0.43	0.77	0.87	3.58	0.78	1.04	0.79	0.66	0.10
st.dev.	0.60	0.88	1.99	3.20	1.00	1.23	n.a.	0.61	0.09
Avg. Millet inc. % of TOT. INC.	0.90	1.58	0.99	2.67	1.49	1.83	n.a.	n.a.	0.17
st.dev.	0.80	2.75	1.24	2.02	1.85	2.70	n.a.	n.a.	0.18
Avg. Maize Cons. % of TOT. INC.	17.76	14.07	10.24	21.67	14.50	11.98	20.65	28.03	29.70
st.dev.	15.81	12.60	9.64	18.98	11.71	9.27	23.62	22.31	25.03
Avg. Millet Cons. % of TOT. INC.	0.73	0.85	0.63	1.80	0.83	0.98	0.40	0.87	0.31
st.dev.	0.72	1.48	0.87	2.68	1.29	1.46	0.58	0.43	0.43
Avg. Sorghum Cons. % of TOT. INC.	0.52	0.52	0.50	2.68	0.59	0.82	0.45	0.80	0.22
st.dev.	0.52	0.66	1.06	3.07	0.95	1.23	0.56	0.44	0.41
Avg. Maize Yield (kg/kgseed)	88.28	87.20	100.10	66.97	99.83	102.78	49.42	52.14	59.07
st.dev.	62.03	63.67	71.17	89.28	72.86	62.06	33.02	32.34	36.93
Avg. Sorghum Yield (kg/kgseed)	22.31	45.63	47.36	60.74	44.53	52.32	120.00	32.50	4.67
st.dev.	27.06	124.21	102.62	55.32	84.38	56.39	n.a.	10.61	4.62
Avg. Millet Yield (kg/kgseed)	23.95	45.15	28.16	34.24	43.73	50.34	n.a.	n.a.	4.00
st.dev.	24.65	120.08	33.87	36.36	54.99	64.28	n.a.	n.a.	2.83
Avg. Maize Price (KSH/kg)	10.67	11.54	12.32	11.06	11.89	13.02	n.a.	19.58	14.32
st.dev.	1.94	1.98	2.55	1.48	2.35	2.99	n.a.	5.70	3.76
Avg. Sorghum Price (KSH/kg)	12.00	14.72	17.32	28.44	18.31	19.89	n.a.	n.a.	12.50
st.dev.	n.a.	10.56	7.40	21.43	5.19	8.34	n.a.	n.a.	n.a.
Avg. Millet Price (KSH/kg)	17.68	20.94	25.11	27.03	17.29	22.21	n.a.	n.a.	n.a.
st.dev.	10.70	8.31	8.56	12.74	8.58	7.05	n.a.	n.a.	n.a.

Notes: KSH- Kenyan Shillings (1 US dollar = 74 KSH)

Table 18. Characteristics of Maize, Sorghum and Millet Producing Households in Kenya

	Central (90 obs.)			Eastern (92 obs.)			Nyanza (97 obs.)			Rift Valley (64 obs.)			Western (111 obs.)		
	small	*med*	*large*	*small*	*med*	*large*	*small*	*med*	*large*	*small*	*med*	*large*	*small*	*med*	*large*
Avg. Maize Inc.	7,324	12,624	13,001	9,551	10,310	22,893	7,218	10,133	18,715	24,703	49,435	91,989	7,725	33,810	65,117
CV	0.55	0.54	0.51	0.67	0.54	0.58	0.63	0.61	0.58	0.65	0.65	0.58	0.59	0.56	0.51
Avg. Sorghum Inc.	n.a	n.a	326	869	1,087	2,313	2,134	2,160	3,747	757	1,262	1,810	1,498	1,846	3,896
CV	n.a	n.a	n.a	0.68	0.67	0.55	0.55	0.85	0.67	0.69	0.97	0.48	0.48	0.38	0.65
Avg. Millet Inc.	n.a	n.a	n.a	609	1,524	1,946	2,303	3,008	2,174	1,040	3,211	3,956	2,660	9,068	5,529
CV	n.a	n.a	n.a	n.a	n.a	1.09	0.86	0.52	0.59	0.54	0.69	0.77	0.94	0.71	0.49
Avg. Maize Cons.	9,151	11,983	11,585	9,926	10,927	18,560	10,380	13,256	15,417	19,939	26,942	39,006	10,905	22,129	36,100
CV	0.54	0.51	0.45	0.64	0.49	0.48	0.53	0.54	0.47	0.53	0.68	0.66	0.61	0.57	0.50
Avg. Sorghum Cons.	141	153	141	285	491	938	1,982	2,345	2,518	667	836	927	1,235	729	2,167
CV	0.82	0.68	0.66	0.35	0.79	0.88	0.72	0.78	0.77	0.69	0.64	0.70	0.56	0.68	0.95
Avg. Millet Cons.	141	153	126	297	335	550	1,541	1,931	882	846	1,414	2,777	1,537	5,006	3,771
CV	0.82	0.68	0.66	0.35	0.74	0.70	0.78	0.69	0.75	0.66	0.64	0.81	0.56	0.81	0.55
Avg. TOTAL INCOME	161,195	241,172	299,575	181,038	176,082	301,126	67,259	120,406	179,188	122,112	198,380	563,800	74,072	177,122	314,799
CV	0.40	0.38	0.39	0.47	0.40	0.53	0.58	0.64	0.53	0.57	0.47	0.49	0.59	0.46	0.38
Avg. Maize inc. % of TOT. INC.	7.44	7.66	5.95	7.40	9.10	11.46	17.51	13.83	17.94	23.00	24.11	20.77	13.47	20.73	21.48
CV	0.54	0.52	0.44	0.63	0.55	0.59	0.56	0.67	0.51	0.49	0.49	0.54	0.59	0.58	0.50
Avg. Sorghum inc. % of TOT. INC.	n.a	n.a	0.28	0.68	1.24	1.30	6.97	3.19	3.83	0.78	0.80	0.46	4.29	1.00	1.46
CV	n.a	n.a	n.a	0.46	0.67	0.85	0.62	0.78	0.68	0.43	0.31	0.53	0.58	0.46	0.64
Avg. Millet inc. % of TOT. INC.	n.a	n.a	n.a	0.67	1.44	0.99	8.82	4.06	1.26	1.65	1.87	1.16	5.79	3.52	1.78
CV	n.a	n.a	n.a	n.a	n.a	1.34	0.85	0.48	0.64	0.82	0.72	0.80	0.71	0.76	0.57
Avg. Maize Cons. % of TOT. INC.	10.13	7.59	10.96	8.84	10.54	11.54	37.54	24.73	18.40	27.99	14.50	8.93	29.29	18.02	13.91
CV	0.42	0.53	0.51	0.63	0.51	0.72	0.58	0.63	0.59	0.59	0.98	1.31	0.41	0.85	0.84
Avg. Millet Cons. % of TOT. INC.	0.13	0.09	0.04	0.27	0.28	0.24	7.85	3.21	0.75	1.27	0.96	0.81	3.76	1.89	1.22
CV	0.80	0.47	0.85	0.44	0.60	0.64	0.90	0.79	0.65	0.64	0.63	0.86	0.54	0.79	0.69
Avg. Sorghum Cons. % of TOT. INC.	0.13	0.09	0.06	0.20	0.49	0.56	8.32	3.91	2.85	0.96	0.57	0.25	3.60	0.60	1.00
CV	0.80	0.47	0.87	0.40	0.70	0.92	0.77	0.87	0.74	0.52	0.58	0.77	0.64	0.69	0.94
Avg. Maize Yield (kg/kgseed)	74.1	76.9	60.3	75.9	56.9	56.0	57.7	54.1	53.8	97.2	128.8	123.7	56.8	95.4	94.9
CV	0.53	0.54	0.49	0.65	0.54	0.63	0.57	0.59	0.53	0.51	0.67	0.50	0.70	0.60	0.46
Avg. Sorghum Yield (kg/kgseed)	n.a	n.a	n.a	400.7	80.5	61.0	38.0	35.8	66.9	15.0	37.0	48.2	40.1	34.7	127.3
CV	n.a	n.a	n.a	0.40	0.53	0.66	0.58	0.82	0.59	0.17	0.68	0.56	0.59	1.20	0.57
Avg. Millet Yield (kg/kgseed)	n.a	n.a	n.a	63.2	65.6	49.6	34.6	19.9	50.1	22.1	29.3	36.6	44.5	65.1	85.8
CV	n.a	n.a	n.a	n.a	n.a	0.21	0.60	0.52	0.76	0.95	0.55	0.58	0.19	0.76	0.51
Avg. Maize Price (KSH/kg)	11.4	13.6	11.8	12.1	12.1	11.3	22.4	12.3	12.1	9.3	10.7	11.2	10.2	11.1	11.4
CV	0.17	0.20	0.43	0.19	0.24	0.20	0.29	0.18	0.17	0.18	0.21	0.20	0.12	0.22	0.21
Avg. Sorghum Price (KSH/kg)	n.a	n.a	n.a	17.7	8.7	9.2	11.1	13.1	11.4	15.0	12.2	14.9	20.1	15.8	14.2
CV	n.a	n.a	n.a	n.a	0.42	0.15	0.46	0.60	0.19	n.a	n.a	0.71	0.45	n.a	0.37
Avg. Millet Price (KSH/kg)	n.a	n.a	n.a	12.7	20.0	12.2	15.9	19.9	22.4	n.a	19.9	23.1	20.4	19.3	53.0
CV	n.a	n.a	n.a.	n.a	n.a	0.32	0.49	0.37	0.07	n.a	0.30	0.19	n.a	0.25	0.51

Notes: KSH- Kenyan Shillings (1 $US dollar = 74 KSH)

Table 19. Characteristics of Maize, Sorghum and Millet Producing Households in Uganda in 2005/06 in the Central, Eastern, Northern and Western Region

	Central (979 obs.)			Eastern (1340 obs.)			Northern (839 obs.)			Western (1109 obs.)		
	small	*med*	*large*	*small*	*med*	*large*	*small*	*med*	*large*	*small*	*med*	*large*
Avg. Maize Price (USH/kg)	510	689	596	746	459	789	487	536	585	556	532	684
st.dev.	231	422	346	385	100	574	193	363	420	248	298	470
Avg. Sorghum Price (USH/kg)	667	508	519	480	758	589	491	432	509	828	641	774
st.dev.	289	205	222	142	378	286	191	155	206	521	334	445
Avg. Millet Price (USH/kg)	433	566	575	571	614	561	461	429	505	502	666	486
st.dev.	82	361	318	361	340	252	128	219	288	188	300	85
Avg. Maize Yield (kg/ha)	1,832	1,862	1,955	1,723	1,578	1,495	1,399	1,311	1,256	2,260	1,964	1,983
st.dev.	1,137	1,062	1,175	1,024	878	805	1,256	948	888	1,600	1,209	1,191
Avg. Sorghum Yield (kg/ha)	959	917	931	1,011	916	909	633	697	585	1,155	1,220	1,182
st.dev.	n.a.	289	1,661	404	448	658	266	333	402	913	743	462
Avg. Millet Yield (kg/ha)	1,507	1,097	1,041	767	959	951	1,069	760	695	1,211	1,098	1,055
st.dev.	332	1,028	1,180	539	678	670	640	333	732	198	653	1,032
Avg. TOTAL Inc.	1,388,526	2,118,807	3,358,217	826,964	1,495,477	3,208,365	746,684	1,001,590	1,932,700	1,205,053	1,443,183	3,384,410
st.dev.	3,197,368	5,476,555	5,341,986	1,596,840	3,855,598	5,505,201	1,905,949	2,264,077	5,665,021	2,797,614	2,712,362	6,896,130
Avg. Maize inc. (USH)	48,956	87,455	266,249	73,549	130,625	374,495	29,986	86,758	107,644	40,418	82,740	235,148
st.dev.	139,496	153,499	566,074	167,289	174,077	1,006,023	39,934	217,970	226,868	57,789	185,829	641,381
Avg. Sorghum inc. (USH)	8,364	19,321	47,223	17,269	39,170	46,426	20,655	24,756	45,376	53,552	44,010	86,878
st.dev.	9,405	37,030	69,062	18,929	112,986	55,553	23,404	30,067	81,070	241,569	68,532	261,723
Avg. Millet inc. (USH)	37,733	53,456	38,667	31,376	56,939	102,696	35,217	46,332	61,650	89,399	61,447	127,744
st.dev.	38,808	65,098	43,402	36,218	72,708	142,094	47,295	51,118	79,652	500,342	75,700	436,289
Avg. Maize cons. (USH)	119,438	126,208	142,318	117,987	92,829	194,346	88,938	73,998	103,834	97,987	102,555	107,064
st.dev.	153,379	167,091	180,257	146,183	107,804	787,298	132,873	171,966	168,791	117,157	167,439	143,098
Avg. Sorghum Cons. (USH)	32,378	21,067	38,341	52,666	51,644	49,615	23,941	26,267	50,235	52,308	66,929	67,709
st.dev.	26,220	15,127	42,986	68,367	72,324	50,179	26,496	43,663	61,217	75,672	78,793	79,128
Avg. Millet Cons. (USH)	36,667	118,320	33,444	37,482	45,281	70,459	68,807	66,927	95,280	56,360	42,809	182,449
st.dev.	37,859	82,587	36,035	37,568	39,969	83,711	101,764	73,147	136,360	46,819	42,361	694,378
Avg. Maize inc. % of TOT. INC.	9.6	9.2	11.9	16.7	17.3	16.0	10.1	12.6	10.8	8.5	9.5	9.1
st.dev.	15.4	13.4	15.2	19.1	17.7	17.3	15.0	13.6	12.9	11.4	12.9	14.1
Avg. Sorghum inc. % of TOT. INC.	2.6	3.7	4.6	6.2	5.5	4.2	13.7	7.6	6.3	7.3	6.7	5.1
st.dev.	3.4	7.1	9.4	7.9	8.2	6.3	20.8	11.5	8.4	9.9	8.9	6.7
Avg. Millet inc. % of TOT. INC.	6.5	8.1	4.2	10.0	8.7	7.6	11.5	8.7	6.6	9.3	6.3	5.1
st.dev.	6.3	8.9	5.1	10.2	9.2	8.6	11.8	9.4	8.0	12.2	5.9	6.5
Avg. Maize Cons. % of TOT. INC.	33.8	16.7	14.1	43.3	15.6	9.8	35.1	24.2	17.2	26.2	13.0	7.8
st.dev.	86.2	32.3	36.4	105.5	29.2	14.6	65.8	74.0	33.4	62.4	20.5	13.1
Avg. Millet Cons. % of TOT. INC.	2.6	3.7	4.6	6.2	5.5	4.2	13.7	7.6	6.3	7.3	6.7	5.1
st.dev.	3.4	7.1	9.4	7.9	8.2	6.3	20.8	11.5	8.4	9.9	8.9	6.7
Avg. Sorghum Cons. % of TOT. INC.	6.5	8.1	4.2	10.0	8.7	7.6	11.5	8.7	6.6	9.3	6.3	5.1
st.dev.	6.3	8.9	5.1	10.2	9.2	8.6	11.8	9.4	8.0	12.2	5.9	6.5

Notes: USH – Uganda Shillings (1 US dollar = 1701 USH)

Table 20. Characteristics of Maize, Sorghum and Millet Producing Households in Amhara Region- Ethiopia in 2000

	Amhara (216 obs)		
	small	*med*	*large*
Avg. Maize Price (ETB/kg)	0.82	1.00	0.89
st.dev.	0.38	0.68	0.28
Avg. Sorghum Price (ETB/kg)	1.36	1.00	1.17
st.dev.	0.53	0.37	0.26
Avg. Millet Price (ETB/kg)	1.00	0.89	0.94
st.dev.	n.a.	0.26	0.28
Avg. Maize Yield (kg/ha)	926	1,203	1,182
st.dev.	1,261	1,026	1,104
Avg. Sorghum Yield (kg/ha)	672	914	765
st.dev.	440	656	534
Avg. Millet Yield (kg/ha)	763	1,219	1,173
st.dev.	559	1,138	1,050
Avg. TOTAL Inc. (ETB)	3,389	5,460	6,998
st.dev.	4,818	5,685	3,858
Avg. Maize inc. (ETB)	279	464	905
st.dev.	540	592	834
Avg. Sorghum inc. (ETB)	351	732	985
st.dev.	233	812	782
Avg. Millet inc. (ETB)	123	326	669
st.dev.	96	201	682
Avg. Maize inc. % of TOT. INC.	8.23	8.51	12.93
st.dev.	8.81	10.18	13.66
Avg. Sorghum inc. % of TOT. INC.	10.36	13.40	14.08
st.dev.	17.51	18.77	16.63
Avg. Millet inc. % of TOT. INC.	3.62	5.98	9.55
st.dev.	4.09	5.82	6.92
Avg. Maize cons. (ETB)	164	261	646
st.dev.	181	255	572
Avg. Sorghum Cons. (ETB)	159	237	879
st.dev.	100	249	590
Avg. Millet Cons. (ETB)	58	162	317
st.dev.	50	136	260
Avg. Maize Cons. % of TOT. INC.	7.60	7.21	9.56
st.dev.	8.48	6.56	7.29
Avg. Sorghum Cons. % of TOT. INC.	10.31	10.98	22.77
st.dev.	10.45	18.84	19.31
Avg. Millet Cons. % of TOT. INC.	4.58	3.81	6.24
st.dev.	2.57	2.86	4.49

Notes: ETB – Ethiopian Birr (1 US dollar = 9.1 ETB)

Table 21. Adoption Rates in Each Country (Percentages)

	Maize	Sorghum	Millet
Kenya-Low Drought Risk	30	20	20
Kenya-Medium Drought Risk	40	30	30
Kenya-High Drought Risk	50	40	40
Uganda-Low Drought Risk	20	10	10
Uganda-Medium Drought Risk	30	15	15
Uganda-High Drought Risk	40	20	20
Ethiopia-Low Drought Risk	15	6	6
Ethiopia-Medium Drought Risk	20	8	8
Ethiopia-High Drought Risk	25	10	10

Table 22. Demand and Supply Elasticities for Each Country

	Maize		Sorghum		Millet	
	Demand	Supply	Demand	Supply	Demand	Supply
Kenya	-0.4	0.68	-0.3	0.35	-0.3	0.35
Uganda	-0.075	0.31	-0.3	0.35	-0.3	0.35
Ethiopia	-0.4	0.08	-0.3	0.35	-0.3	0.35

Table 23. Kenya- Annual Market Level Benefits from Drought Resistance Research (thousand $US)

Benefits from Mean Yield Increases from Public and Private Sector Research (thousand $US)									
	Maize-Public		Sorghum-Public		Millet-Public		Maize-Private		
	Pr. Y	Cs. Y	Pr. Y	Cs. Y	Pr. Y	Cs. Y	Pr. Y	Cs. Y	Π
Central-Medium	182	309	62	73	1	1	180	306	306
Central- High	189	321	2	2	1	1	190	324	273
Eastern-Medium	65	111	3	4	8	9	64	110	120
Eastern-High	1,155	1,963	55	64	67	78	1,165	1,981	1,420
Nyanza-Medium	509	866	8	9	47	55	505	858	811
Rift Valley-Medium	1,740	2,958	86	100	81	94	1,723	2,930	3,769
Rift Valley-High	537	913	51	60	31	37	542	922	900
Coastal-High	4,035	6,859	281	328	6	8	4,071	6,921	5,418
Western-Medium	504	857	2	3	1	1	499	849	1,273
Benefits from Yield Variance Reductions from Public and Private Sector Research (thousand $US)									
	Maize-Public		Sorghum-Public		Millet-Public		Maize-Private		
	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Π
Central-Medium	5	10	24	35	0.3	0.4	6	14	-
Central- High	6	13	1	1	1	1	7	16	-
Eastern-Medium	2	5	1	2	0.4	1	3	7	-
Eastern-High	58	127	19	27	5	9	72	179	-
Nyanza-Medium	204	443	162	222	1	1	251	547	-
Rift Valley-Medium	19	42	7	9	33	44	25	55	-
Rift Valley-High	51	113	24	37	57	75	67	150	-
Coastal-High	19	41	17	24	37	45	28	62	-
Western-Medium	21	46	3	3	0.3	0.5	27	60	-
Total	9,301	15,997	807	1,001	378	460	9,425	16,289	14,290

Table 24. Kenya- Annual Representative Producer Household Benefits ($US)

Representative Producer Household Benefits from Mean Yield Increases ($US)												
	Maize-Public			Sorghum-Public			Millet-Public			Maize-Private		
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Central-Medium	2.6	6.1	7.0	1.0	1.4	2.7	1.0	6.6	1.0	2.7	6.5	7.5
Central- High	2.6	6.2	7.2	1.5	2.1	4.0	1.1	7.1	1.1	2.8	6.6	7.6
Eastern-Medium	3.7	5.6	20.6	0.9	1.0	1.9	1.1	7.0	1.1	3.9	6.0	22.0
Eastern-High	4.9	7.4	27.1	1.2	1.4	2.7	1.3	8.7	1.3	5.2	7.8	28.8
Nyanza-Medium	4.4	8.3	12.8	3.3	4.0	5.2	2.3	3.3	7.5	4.7	8.8	13.7
Rift Valley-Med.	3.8	7.5	18.4	1.4	1.9	2.6	0.9	3.3	3.7	4.0	8.0	19.6
Rift Valley-High	4.3	8.5	20.8	2.1	2.8	3.9	1.1	4.1	4.6	4.5	9.1	22.2
Coastal-High	3.3	4.8	43.4	0.4	0.8	2.0	-	-	0.9	3.5	5.1	46.2
Western-Medium	3.0	4.6	12.5	2.1	3.8	5.3	1.7	3.9	5.2	3.2	5.0	13.4
Representative Producer Household Benefits from Yield Variance Reductions ($US)												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Central-Medium	2.0	6.0	5.7	0.2	1.5	1.4	1.1	1.8	0.6	2.7	8.0	7.6
Central- High	2.8	8.3	7.9	0.5	2.5	2.5	1.8	2.9	1.4	3.5	10.4	9.9
Eastern-Medium	4.8	5.5	16.1	0.4	1.2	3.1	0.5	1.1	0.3	6.4	7.3	21.5
Eastern-High	6.6	7.7	22.4	0.8	2.2	5.1	0.7	1.4	0.4	8.3	9.8	28.3
Nyanza-Medium	3.3	9.3	6.7	2.8	4.5	4.4	0.3	0.3	0.9	4.5	12.4	8.9
Rift Valley-Med.	4.8	12.8	21.6	0.1	0.7	0.7	2.0	1.4	2.3	6.4	17.1	28.8
Rift Valley-High	6.7	17.4	29.8	0.3	1.0	1.1	3.1	2.5	4.0	8.5	22.0	38.0
Coastal-High	3.9	4.0	40.1	0.5	1.0	3.4	-	-	0.8	4.8	5.0	50.1
Western-Medium	5.6	9.2	15.0	0.4	1.5	0.9	0.8	4.2	2.2	7.4	12.2	19.9

Table 25. Kenya – Annual Aggregate Benefits based on Producer Household Aggregation (thousand $US)

Aggregate Producer Household Benefits from Mean Yield Increases (thousand $US)												
	Maize-Public			Sorghum-Public			Millet-Public			Maize-Private		
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Central-Medium	42	79	44	4.3	13	42	0.1	0.5	0.2	48	90	50
Central- High	40	76	42	0.1	0.3	1.1	0.2	0.7	0.3	45	85	47
Eastern-Medium	6	8	45	0.2	0.6	2.1	1.0	4.6	1.7	7	9.5	51
Eastern-High	98	136	733	2.2	6.7	22	8.2	39	14	110	152	822
Nyanza-Medium	102	173	187	2.7	2.8	2.1	10.0	9.7	25	117	198	215
Rift Valley-Med.	144	353	1,079	12.6	27	42	7.7	26	44	165	405	1,239
Rift Valley-High	41	101	308	5.8	12	19	2.9	9.8	16	46	113	346
Coastal-High	203	351	2,825	12.8	51	192	-	-	6.0	228	394	3,168
Western-Medium	54	104	298	0.3	0.7	1.1	0.1	0.2	0.5	62	120	342
Aggregate Producer Household Benefits from Yield Variance Reductions (thousand $US)												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Central-Medium	71	164	75	0.2	8.4	40.7	0.2	0.3	0.2	94	219	100
Central- High	87	203	93	0.1	0.2	1.2	0.4	0.5	0.6	109	253	116
Eastern-Medium	16	17	74	0.2	0.5	6.4	0.8	1.3	0.7	22	23	99
Eastern-High	267	284	1,215	2.5	6.0	71.6	7.2	11.4	7.8	337	361	1,535
Nyanza-Medium	164	412	206	4.3	5.8	3.4	2.6	1.9	5.9	219	549	274
Rift Valley-Med.	392	1,270	2,691	1.9	8.2	20.6	32.1	20.2	49.7	522	1,693	3,586
Rift Valley-High	129	412	884	1.3	3.8	9.9	14.1	10.4	25.2	164	521	1,128
Coastal-High	483	581	5,231	27	28	588	-	-	9.7	603	725	6,531
Western-Medium	214	435	753	0.1	0.2	0.4	0.1	0.4	0.4	285	579	1,003
Total	2,553	5,158	16,782	79	176	1,065	88	137	208	3,184	6,490	20,653

Table 26. Uganda – Annual Market Level Benefits from Drought Resistance Research (thousand $US)

Benefits from Mean Yield Increases from Public and Private Sector Research (thousand $US)									
	Maize-Public		Sorghum-Public		Millet-Public		Maize-Private		
	Pr. Y	Cs. Y	Pr. Y	Cs. Y	Pr. Y	Cs. Y	Pr. Y	Cs. Y	Π
Central-Low	158	652	12	14	35	41	82	337	331
Central- Medium	123	508	18	22	15	17	99	408	198
Eastern-Medium	1,175	4,858	281	328	621	724	945	3,905	1,702
Northern-Medium	336	1,391	390	455	415	484	270	1,118	604
Northern-High	522	2,159	44	52	31	36	458	1,895	677
Western - Low	24	97	33	39	19	22	12	50	50
Western-Medium	329	1,361	195	227	231	270	265	1,094	537
Benefits from Yield Variance Reductions from Public and Private Sector Research (thousand $US)									
	Maize-Public		Sorghum-Public		Millet-Public		Maize-Private		
	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Π
Central-Low	473	454	3	5	8	12	706	678	-
Central- Medium	527	504	7	10	5	7	697	667	-
Eastern-Medium	9,188	8,738	110	160	32	54	9,188	8,738	-
Northern-Medium	1,637	1,562	186	281	299	395	2,729	2,593	-
Northern-High	3,727	3,524	19	27	38	46	4,607	4,359	-
Western - Low	81	78	22	28	4	6	121	116	-
Western-Medium	2,119	2,023	258	322	72	107	2,795	2,670	-
Total	20,419	27,911	1,578	1,970	1,826	2,223	22,974	28,628	4,097

Table 27. Uganda – Annual Representative Producer Household Benefits ($US)

	Maize-Public			Sorghum-Public			Millet-Public			Maize Private		
Representative Producer Household Benefits from Mean Yield Increases ($US)												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Central-Low	4.3	9.1	22.5	2.2	4.2	14.9	2.8	5.2	12.4	2.8	5.9	14.5
Central- Medium	4.9	10.4	25.8	2.8	5.4	19.2	3.8	7.0	16.8	4.6	9.6	23.9
Eastern-Medium	10.9	23.7	54.2	8.7	16.8	21.9	9.4	10.7	16.5	10.1	22.0	50.2
Northern-Medium	7.5	13.5	21.4	8.3	12.0	17.4	5.3	11.5	16.3	7.0	12.5	19.9
Northern-High	8.9	15.9	25.3	10.0	14.5	21.0	5.4	11.7	16.6	8.7	15.6	24.9
Western - Low	3.6	7.0	18.5	7.9	11.1	23.6	10.8	14.5	24.4	2.3	4.5	12.0
Western-Medium	4.1	8.0	21.3	7.5	10.5	22.3	7.2	9.7	16.4	3.8	7.4	19.7
Representative Producer Household Benefits from Yield Variance Reductions ($US)												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Central-Low	2.4	3.6	6.6	0.5	1.7	3.5	1.2	2.0	0.4	3.5	5.3	9.8
Central- Medium	4.9	14.3	13.9	1.1	3.5	7.1	1.9	3.1	0.7	6.5	9.7	18.5
Eastern-Medium	8.6	14.3	31.1	2.0	3.3	5.4	1.5	2.0	0.7	9.7	15.6	34.6
Northern-Medium	2.9	6.1	8.0	4.2	3.2	5.1	4.3	1.8	2.8	4.5	9.2	12.3
Northern-High	6.4	12.4	17.7	8.5	6.3	10.1	6.2	2.9	4.5	8.0	15.4	21.9
Western - Low	2.7	3.0	5.1	1.0	1.3	2.4	1.5	1.1	1.8	4.0	5.3	7.6
Western-Medium	6.0	7.2	13.6	3.8	4.2	7.5	2.3	1.6	2.7	8.0	9.5	18.0

Table 28. Uganda – Annual Aggregate Producer Benefits based on Household Aggregation (thousand $US)

	Maize			Sorghum			Millet			Maize Private		
Aggregate Producer Benefits from Mean Yield Increases (thousand $US)												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Central-Low	12	30	102	0.4	2.6	8.5	4.1	6.6	24	14	33	113
Central- Medium	8.9	21	73	0.6	4.1	13	1.7	2.8	10	12	29	98
Eastern-Medium	118	249	617	36	93	145	104	132	371	159	336	830
Northern-Medium	42	85	155	50	128	202	45	131	229	57	114	208
Northern-High	55	110	201	12	12	18	3.4	9.7	17	74.0	148	271
Western - Low	2.1	4.8	15	4.6	7.2	21.1	3.7	5.7	9.4	2.4	5	16
Western-Medium	27	61	187	26	42	122	45	68	112	37	82	252
Aggregate Producer Benefits from Yield Variance Reductions (thousand $US)												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Central-Low	32	55	138	0.1	2	4	4	5	2	48	82	206
Central- Medium	39	131	175	1	5	10	2	2	1	52	89	232
Eastern-Medium	415	669	1,574	17	36	72	34	50	30	466	731	1,754
Northern-Medium	73	171	257	52	68	118	75	42	80	113	257	397
Northern-High	180	389	636	20	11	17	8	5	9	224	482	788
Western - Low	7	9	19	1	2	4	1	1	1	11	17	28
Western-Medium	177	242	532	27	34	83	29	23	37	235	321	704
Total	1,189	2,228	4,681	249	447	838	360	484	933	1,504	2,727	5,898

Table 29. Ethiopia-Amhara Region – Annual Market Level Benefits (thousand $US)

Benefits from Mean Yield Increases from Public and Private Sector Research (thousand $US)									
	Maize-public		Sorghum-Public		Millet-Public		Maize-Private		
	Pr. Y	Cs. Y	Pr. Y	Cs. Y	Pr. Y	Cs. Y	Pr. Y	Cs. Y	Π
Amhara - Medium	3,235	647	319	372	57	66	2,560	512	2,779
Amhara - High	61	12	49	58	0.13	0.15	10	52	67
Benefits from Yield Variance Reductions from Public and Private Sector Research (thousand $US)									
	Maize-public		Sorghum-Public		Millet-Public		Maize-Private		
	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Π
Amhara - Medium	4,819	4,212	158	223	19	28	6,353	5,587	-
Amhara - High	163	111	40	51	0.07	0.10	201	138	-
Total	8,278	4,982	566	704	76	94	9,124	6,289	2,846

Table 30. Ethiopia-Amhara Region – Annual Representative Producer Household Benefits ($US)

Representative Producer Benefits from Mean Yield Increases ($US)												
	Maize-Public			Sorghum-Public			Millet-Public			Maiz- Private		
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Amhara - Medium	8.3	9.5	19.6	8.1	13.4	26.6	5.2	7.0	12.7	7.5	8.6	17.7
Amhara - High	6.9	7.9	16.2	12.5	20.8	41.2	6.9	9.3	16.9	6.5	7.5	15.4
Representative Producer Benefits from Yield Variance Reductions ($US)												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Amhara - Medium	2.2	3.9	7.2	4.6	10.8	11.4	0.6	1.6	1.1	3.0	5.2	9.6
Amhara - High	4.3	7.5	13.8	7.2	16.1	17.5	0.9	2.3	1.6	5.3	9.4	17.1

Table 31. Ethiopia – Amhara Region – Annual Aggregated Producer Benefits based on Household Aggregation (thousand $US)

	Maize-Public			Sorghum-Public			Millet-Public			Maize-Private		
Aggregated Producer Benefits from Mean Yield Increases (thousand $US)												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Amhara - Medium	423	900	1,891	89	93	132	7	14	35	389	828	1,739
Amhara - High	7.9	17	35	14	14	20	0.02	0.03	0.08	8	16	34
Aggregated Producer Benefits from Yield Variance Reductions (thousand $US)												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Amhara - Medium	132	434	807	107	157	118	2	7	6	176	577	1,073
Amhara - High	6	19	35	16	23	18	0.004	0.02	0.02	7	23	43
Total	569	1,370	2,768	226	288	288	9	21	41	580	1,444	2,890

Table 32. Kenya- Sensitivity Analysis on Annual Mean Yield Benefits from Public Sector Research (thousand $US)

	Maize		Sorghum		Millet	
	Pr. Y	Cs. Y	Pr. Y	Cs. Y	Pr. Y	Cs. Y
			Initial Results			
Eastern-Medium	65	111	3	4	8	9
Eastern-High	1,155	1,963	55	64	67	78
			Increases by 50 percent in the Adoption Rates Employed			
Eastern-Medium	98	166	5	5	11	13
Eastern-High	1,742	2,961	82	96	101	117
			Increases by 50 percent in the Mean Yield Employed			
Eastern-Medium	98	166	5	5	11	13
Eastern-High	1,742	2,961	82	96	101	117

Table 33. Kenya- Sensitivity Analysis on Annual Benefits from Private Sector Research in Maize (thousand $US)

	Maize		
	Initial Results		
	Pr. Y	Cs. Y	Profits
Eastern-Medium	64	110	120
Eastern-High	1,165	1,981	1,420
	Increases of 50 percent in the Adoption Rates Employed		
Eastern-Medium	99	168	180
Eastern-High	1,792	3,048	2,130
	Increases of 50 percent in Mean Yields Employed		
Eastern-Medium	116	198	120
Eastern-High	2,006	3,410	1,420
	Increases in Seed Demand Elasticity from -2 to -3		
Eastern-Medium	82	140	60
Eastern-High	1,387	2,358	710

Table 34. Kenya- Sensitivity Analysis on Annual Benefits from Yield Variance Reduction Benefits (thousand $US)

	Public Sector Research						Private Sector Research	
	Maize		Sorghum		Millet		Maize	
	Initial Results							
	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Pr. RB	Cs. RB	Pr. RB	Cs. RB
Eastern-Medium	2	5	1	2	0.4	1	3	7
Eastern-High	58	127	19	27	5	9	72	179
	Decreases of 50 percent in the Supply Elasticity Employed							
Eastern-Medium	28	47	5	5	1	2	37	61
Eastern-High	782	1,149	81	80	17	26	956	1,624
	Increases of 50 percent in the Demand Elasticity Employed							
Eastern-Medium	1	4	1	1	0.2	0.4	1	5
Eastern-High	21	90	10	18	2	6	26	128
	Increases of 50 percent in the Variance Reductions Employed							
Eastern-Medium	3	8	2	3	0.6	1.0	4	10
Eastern-High	85	185	28	39	8	13	104	247

Table 35. Kenya- Sensitivity Analysis on Annual Aggregate Benefits based on Producer Household Aggregation

Benefits from Mean Yield Increases based on Household Aggregation (thousand $US)												
	Maize-Public			Sorghum-Public			Millet-Public			Maize-Private		
Initial Results												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Eastern-Medium	6	8	45	0.2	0.6	2.1	1.0	4.6	1.7	7	9.5	51
Eastern-High	98	136	733	2.2	6.7	22	8.2	39	14	110	152	822
Increases of 50 percent in the Mean Yields Employed												
Eastern-Medium	9	12	64	0.3	0.9	3.0	1.4	6.8	2.4	11	15	83
Eastern-High	134	185	1,000	3.2	9.6	31.0	11.9	56.9	20.5	161	223	1,202
Increases of 50 percent in Adoption Rates Employed												
Eastern-Medium	9	12	64	0.3	0.9	3.0	1.4	6.8	2.4	10	13	71
Eastern-High	134	185	1,000	3.2	9.6	31.0	11.9	56.9	20.5	144	200	1,078
Benefits from Yield Variance Reductions based on Household Aggregation (thousand $US)												
Initial Results												
	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large	Small	Med.	Large
Eastern-Medium	16	17	74	0.2	0.5	6.4	0.8	1.3	0.7	22	23	99
Eastern-High	267	284	1,215	2.5	6.0	71.6	7.2	11.4	7.8	337	361	1,535
Increases of 50 percent in the Yield Variance Reductions Employed												
Eastern-Medium	24	26	111	0.3	1	10	1	2	1	33	34	148
Eastern-High	399	425	1,818	4	9	107	11	17	12	502	535	2,285
Increases of 50 percent in Adoption Rated Employed												
Eastern-Medium	24	26	111	0.3	1	10	1	2	1	33	34	148
Eastern-High	399	425	1,818	4	9	107	11	17	12	502	535	2,285