EX ANTE BENEFITS FROM SITE-SPECIFIC AGRICULTURAL RESEARCH: MAIZE IN KENYA

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ABSTRACT

Technology generation and adoption in sub-Saharan Africa occurs within a complex and rapidly changing environment. This paper uses a spatial multi-market model to examine the potential impact of varietal development activities in six Kenyan maize research target zones with variable rates of human population growth and maize crop area expansion. The results suggest that while maize varietal development activities will continue to generate large economic benefits in several zones, population growth and external trade policy will be the primary determinants of future maize market conditions.
INTRODUCTION

The relationship between technology generation and other components of the agricultural economy is complex. This limits our ability to understand the role of research in the development of the agricultural sector and to meaningfully forecast the benefits from alternative agricultural research options. This limitation is particularly apparent in agricultural production systems with tremendous spatial diversity and subject to rapid changes, as is the case for many agricultural economies in sub-Saharan Africa. Most ex-ante research evaluation and priority setting efforts in sub-Saharan Africa done to date rely principally on the subjective assessments of senior research managers, often using ad hoc scoring approaches. The lack of systematic use of quantitative information on the current environment and explicit estimates of future trends, calls in to question the credibility of these research evaluation and priority setting efforts. The aggregate nature of much of the analysis (e.g., national maize or wheat research programs), provides little guidance for allocating resources by geographic area or major research themes within commodity groups. Many countries are now embarking on a second generation of priority setting efforts. This brings with it a recognition of the need to develop information bases, processes, and methods for ex-ante research evaluation that address the site-specific nature of technology generation as well as the dynamic environment within which technical change occurs.

This paper examines the potential benefits from maize research in Kenya. The example highlights the strong relationship between future benefits from agricultural commodity research and key environmental and policy factors. The next section briefly reviews the role of maize in Kenya along with current research efforts and resources within the public-sector program of maize research. We then present a model of research impact under alternative production environments and market policies. Section four provides new data on the major research and environmental factors associated with the six agroecological zones used to characterize the country's maize research. Simulation results on potential research benefits and future market conditions are presented in section five under alternative external trade policies. In the final section we draw on the Kenyan experience to
reflect on crucial considerations to further develop priority setting processes in sub-Saharan Africa.

MAIZE IN THE KENYAN ECONOMY

Maize is an especially important crop in the Kenyan agricultural economy. It is grown by 90 percent of Kenyan farm households and the majority of production (85 percent) comes from smallholder operations located throughout the diverse agroclimatic conditions found in Kenya. About 45 percent of maize production is consumed on-farm where it is grown. Despite the importance of the commodity, aggregate trends suggest that maize production has failed to keep pace with the growth in domestic demand. According to FAO statistics, there was little change in area harvested between 1972 and 1992, while yield gains led to an annual increase in production of 1.6 percent. This growth in output fell far short of the rate of increase in consumption (2.1 percent per year).

These production and consumption trends have brought Kenya to a crossroads. In an average year the country still meets its domestic demand through local production. But imports are now required to meet food deficits in poor rainfall years. Moreover, the current rapid rate of population growth (3.6 percent per annum), combined with the limited potential for expanding the area under maize, points to the need for sizable increases in productivity if Kenya is to mitigate its increasing reliance on maize imports. Seasonal fluctuations between surpluses and deficits and the substantial variation in maize prices across regions within Kenya has made government efforts to maintain a stable and uniform pan-territorial maize price extremely costly.

Fiscal constraints necessitate a reduction of the scope of government interventions in maize markets. Thus, the internal supply and demand situation, world prices for (white) maize and other staple cereals, and interregional transaction costs are increasingly becoming the primary determinants of domestic maize prices.

In this changing environment, agricultural research remains a cornerstone of government-sponsored efforts to promote domestic food security. The maize program of the Kenya Agricultural Research Institute is currently composed of about
30 full-time equivalent (fte) research officers and has the primary public mandate for the development of maize production technologies. The program has divided this mandate into three major research themes: varietal development, crop management, and technology dissemination. The most visible impact of the program to date has come from its varietal development work which presently involves 10 fte researchers. Since the inception of formal varietal development efforts in the mid-1950s, 11 varieties have been released for high potential areas that subsequently had exceptionally high rates of adoption (Gilbert et al. 1994). Low potential areas have traditionally received less attention from maize breeders, but several suitable varieties have been released, with moderate success in terms of adoption. The maize program needs to clearly understand future sector trends and potential research benefits in each zone in order to effectively utilize its limited human resources. Just as importantly, policy analysts need to understand the role of research and other policy tools in future maize sector development.

MODELLING THE ECONOMIC BENEFITS OF MAIZE RESEARCH

Agricultural research is a long-term investment. The potential returns to that investment can best be understood in relation to the future environment for maize production and the potential role for research within that environment. There are various factors that will affect the future consequences of maize research in Kenya. These include the ability of the research program to generate improved varieties that are adopted by farmers, the rate of growth of population (given its effect on both the demand for maize and the area under maize cultivation), market conditions (including trade policies), and the transaction costs associated with moving maize between surplus and deficit regions within Kenya. We now briefly describe a multi-market, equilibrium displacement model that accounts for these various factors when simulating the potential benefits from research for specific agroecological zones for 30 years into the future. The model described here is an adaptation of the multi-market model presented in Alston, Norton, and Pardey (1996, chap. 5)

Technology Generation and Adoption

Generating new technologies is an uncertain undertaking that is best
represented as a distribution of possible research outcomes. For commodity research, outcomes are most commonly conceptualized in terms of yield increases -- or, more specifically, adjusted yield increases that reflect yield losses due to pest and disease effects that are averted as a consequence of research -- after accounting for any additional input costs associated with the use of the new technology. The distribution of these gains is most simply specified in terms of the minimum, most likely, and maximum possible yield increases. However, not all potential yield gains above the minimum specified by scientists will finally appear on farmers' fields. Farmers, particularly resource-poor producers, are unlikely to adopt new technologies unless the yield increases exceed some threshold level. This threshold level can depend on factors such as farmers' perceptions about the riskiness of the new technology and the additional production costs involved in realizing the potential yield gains. Technologies whose yield gains fall short of this threshold fail at the on-farm testing and evaluation phase of the research cycle and are generally not released for commercial use. The expected yield gain is therefore best calculated as the product of two parameters: a) the probability of exceeding the threshold gain in yields, $K_i^a$, required for the technology to be released for dissemination, $\Pr(K_i > K_i^a)$, and b) the expected yield increase, conditional on the dissemination threshold being exceeded, $E(K_i | K_i > K_i^a)$. For simplicity, we assume a triangular probability density function when calculating these parameters in this study.

The economic consequences of research will also depend on the rate and extent of adoption of technologies. Thus, it is essential to include an assessment of the likely adoption pattern in an economic assessment of new technologies. The basic characteristics of the adoption profile involves a) an R&D gestation lag, ending with the release of a new technology, and b) several subsequent stages characterized by an initial phase of increasing adoption as a growing number of farmers in the target area become exposed to the technology, a plateau phase wherein most potential users have been exposed to the technology and opted to adopt or otherwise, and, finally, a phase of declining adoption as the old technology is replaced by new technology and becomes obsolete. For ease of calculation, the adoption profile is
presumed to have a trapezoidal form.

Taken together, the technology generation and adoption components determine the rate and magnitude at which research results are translated into yield gains on farmers' fields that can then be expressed as expected reductions in unit costs from research, $K_{it}$, for zone $i$ in period $t$.

$$K_{it} = Pr(K_i > K_i^a)E[K_i | K_i > K_i^a]A_{it}P_{i0} / e_i$$

where $A_{it}$ is the adoption rate as determined by the trapezoid adoption profile, $P_{i0}$ is the zone-specific commodity price for the base year (1995) of the simulation, and $e_i$ is the zone-specific supply elasticity.

Local unit-cost reductions can in turn be expressed as a shift down in the commodity supply curve for a specific agroclimatic zone. The “without research” version of the supply curve is given by

$$Qs_{i0} = \alpha_{i0} + B_iP_{i0}$$

where $Qs_{i0}$ is the base year quantity supplied in zone $i$, $\alpha_{i0}$ is the initial supply intercept, and $B_i$ is the fixed supply slope parameter. A research-induced change in the quantity supplied is specified as an intercept shift in the initial curve

$$Q^*s_{it} = \alpha^*_{it} + B_iP_{it}$$

where $\alpha^*_{it} = \alpha_{i0} + K_{it}B_i$ is the intercept of the “with research” supply curve.

**Population growth effects**

Exogenous shifts in maize demand and supply curves due to the growth in population, are included in this model. The demand curve for zone $i$ in period $t$ is given by

$$Qd_{it} = \gamma_{it} + \delta_iP_{it}$$

where $Qd_{it}$ is the quantity demanded, $\gamma_{it}$ is the demand intercept term, and $\delta_i$ is the slope parameter of the demand curve that is presumed invariant over time. Demand shifts are modelled as shifts in the intercept term of the demand function so that in period $t+1$

$$\gamma_{it+1} = \gamma_{it} + \pi_iQd_{it}$$

where $\pi_i$ is rate of growth in the demand for maize zone $i$. The shift in supply due to
a population-induced expansion in the area sown to maize is expressed in the same manner through the supply curve.

**Transaction costs for maize trade**

Maize prices differ both by zone and over time. Prices in zone $i$ for period $t$, $P_{it}$, are specified in terms of the Nairobi price $P_{nt}$, net of a price wedge, $T_i$. This wedge reflects the transactions costs of moving maize to (or from) the capital city of Nairobi from any particular zone. It is presumed to remain constant in real, absolute terms over time.

$$P_{it} = P_{nt} - T_i.$$

**Market clearing conditions**

For a closed economy, the equilibrium quantities and prices are determined for each period in the with and without research scenarios through the respective market clearing conditions:

$$\sum_{i} Q_{ist} = \sum_{i} Q_{ dit} \quad \text{and} \quad \sum_{i} Q^{R}_{sit} = \sum_{i} Q^{R}_{dit}.$$

If equilibrium quantities differ in the two scenarios, zonal prices will also differ in the without ($P_{it}$) versus with ($P^{w}_{it}$) research scenarios. The structure of a maize economy open to external trade can be incorporated in the model by including a "rest-of-world zone" and an appropriate elasticity of supply from the rest of the world to Kenyan maize markets.$^5$

**Research benefit measures**

Research-induced changes in producer and consumer surplus ($\Delta PS$ and $\Delta CS$) are easily calculated from equilibrium quantities and prices for the with and without research scenarios. The change in producer surplus in a specific zone for a specific year is calculated as

$$\Delta PS_{it} = (K_{it} + P^{w}_{it} - P_{it})(Q_{it} + 0.5(Q^{P}_{it} - Q_{it})).$$

The corresponding change in consumer surplus is

$$\Delta CS_{it} = (P_{it} - P^{w}_{it})(Q_{it} + 0.5(Q^{P}_{it} - Q_{it})).$$

The present values for the streams of producer and consumer surplus changes (VPS
and VCS, respectively) over the 30 year simulation period for each zone are

$$VPS_i = \sum_{t=0}^{30} \Delta PS_{it} / (1 + r)^t$$

and

$$VCS_i = \sum_{t=0}^{30} \Delta CS_{it} / (1 + r)^t$$

where $r$ is the real discount rate for the use of public-sector financial resources. We set this real rate equal to five percent based on the rate the Government of Kenya commonly pays for agricultural sector loans from the World Bank. Changes in economic surplus can be added across zones to estimate the overall (i.e., site-specific and spillover) effects of research that is targeted to a specific zone.

**PARAMETERIZING THE MODEL**

As national agricultural research institutes begin using more structured means to assess their research priorities and to plan their activities, the information required to support these decisions increases substantially. Investments in information in KARI’s maize program involved a) developing a better understanding of the environmental determinants of maize production, b) assessing the potential regarding the generation and adoption of new technologies, and c) gaining an appreciation of the current and future market conditions for maize.

**Environmental Determinants of Maize Production**

To more effectively address its broad mandate, KARI’s maize program drew on a geographic information system to identify six distinct agroclimatic zones for maize that have relatively homogeneous biological (i.e., yield) responses to potential technological innovations. These zones were the low tropics, dry mid-altitude, moist mid-altitude, dry transitional, moist transitional, and highland areas. The three key environmental determinants (i.e., elevation, rainfall, and temperature), and the technical parameters used by the maize program to define these agroecologies are given in table 1. All zones are mutually exclusive in terms of combinations of criteria, except for the moist transitional and high tropics zones which overlap between 1800 and 2000 meters. Within this range, only areas with minimum average temperatures below 11 degrees celsius but above 7 degrees celsius for march through august were assigned to the high tropics zone. A map of the resulting zones is presented in appendix 1. There are presently 10tie scientists from the maize
program engaged in varietal improvement research. The current spatial emphasis of their work was determined by estimating the time spent developing improved varieties for the respective agroecological zones. The current breakdown of activities is: low tropics - 2 fte scientists, dry mid-altitude - 0.5 ftes, moist mid-altitude - 2.5 ftes, dry transitional - 1 fte, moist transitional - 1 fte, high tropics - 3 ftes.

The area sown and the total quantity of maize produced in Kenya were estimated using the Department of Remote Sensing and Resource Surveys 1990 long-rains area estimates (Otichillo and Sinange 1991) and the Kenya Maize Data Base Project (KMDBP) surveys of farmers' yields and the area sown to maize in the second (i.e., short-rain) season of 1992 (table 2). Kenyan maize consumption was estimated on the basis that the aggregate supply of maize equals aggregate demand in years of average rainfall. The quantity of maize consumed in each district was estimated using household maize consumption data from the 1979 Kenya Rural Household Budget Survey and 1989 district-level census records of the number of households per district (CBS 1982 and 1994). Finally, the consumption of maize within an agroclimatic zone was calculated by allocating districts to zones based on corresponding area proportions. The resulting consumption estimates are compared with target zone production estimates in table 2 to derive estimates of the current excess demand of maize by zone.

The map in appendix 1 shows that the dry mid-altitude zone spans the largest area of the country. However, the moist transitional zone is the biggest zone in terms of production, consumption, and population. The high tropics zone ranks second in terms of both production and consumption. Despite its comparatively broad geographic coverage, the dry mid-altitude zone ranks fourth behind the moist mid-altitude zone according to the quantity of maize produced and consumed, and third in terms of population. The dry transitional and low tropics zones are relatively small in terms of both the production and consumption of maize.

Perhaps the most important influence on future Kenyan agriculture is the continuing rapid rate of population growth. Zone-specific population growth rates are calculated from a comparison of 1979 and 1989 district census estimates, again assuming population is proportionally distributed by zone area in each district (CBS
1994). Table 3 shows that between 1979 and 1989 the Nairobi area had the highest rate of population growth, 4.7 percent per annum, while the non-urban, rest-of-
Kenya zone (primarily the northern province districts) had the slowest rate of growth at 1.2 percent per annum. The six maize production zones all had extremely high
rates of population growth during the 1980s, ranging from 3.0 to 3.9 percent per
annum. These recent rates of growth are scaled back by one quarter when
incorporated into our simulation model to reflect projected declines in the rate of
population growth. But even with these more conservative rates, population is
predicted to double within the time frame of our simulations. Since maize is a major
staple crop, the adjusted population growth rates are assumed to translate directly
into equivalent rates of growth in the quantity of maize demanded.

Population growth may also stimulate a further expansion in the area under
maize cultivation although the national statistics suggest there may be little
additional land left to cultivate. Between 1961 and 1974 the area under maize
cultivation in Kenya grew by an average rate of 3.9 percent per year (FAO 1995).
However, between 1974 and 1985 the estimated area under cultivation decreased by
an average of 2.4 percent per year and between 1985 and 1993 there was no growth
in cultivated maize area. The area under maize production for each zone, based on
1987 to 1991 DRSRS long-rain estimates, shows a wide variance around the national
trend (table 3). The only zones with increased maize areas are the two drier zones
(i.e., the dry mid-altitude and dry transitional zones) that support relatively lower
population densities. Some uncultivated land is still available in these zones, but
increasingly only in areas with particularly problematic climate and soils.
Determining the likely limits of expansion in these areas over the next 30 years is an
important empirical question. If growth in the dry transitional zone continued at the
rates evidenced for the recent past (i.e., 6 percent per annum), the proportion of
maize area relative to total area in this zone would significantly exceed the ratio
currently found in the high potential areas by the end of our simulation period. This
is unrealistic. We therefore assumed the rate of area expansion in the dry mid-altitude
and dry transitional zones would fall linearly from their current levels to zero over the
next 30 years. The area sown to maize in the other zones was held constant at
present levels throughout the simulation period.\textsuperscript{9}

**Technology generation and adoption**

Since the outcome of research investments are not realized for many years, ex-ante technology generation and adoption parameters must be based on the subjective opinion of informed sources. The most knowledgeable sources for this type of information are often program experts with vested interests in the outcomes of the priority setting exercise. Priority setting processes must attempt to control for the bias inherent in these subjective estimates of interested parties. The KARI elicitation process incorporated three steps in an effort to control for potential bias. First, the program collected benchmark information on historical yield and production growth trends in the target zones, along with available information on adoption of previously released technologies.\textsuperscript{10} This benchmark information served as a reference point when examining the ex-ante potential for technology generation and adoption. Second, a Priority Setting Working Group composed of key program scientists from different disciplines and regions of Kenya jointly reviewed the major constraints to maize production in each zone and identified the key problems to be addressed through thematic research.\textsuperscript{11} The potential research impact from addressing these constraints was then reviewed by the group through a structured elicitation process. Elicitation within a group setting established some control on potential bias. If an individual scientist behaved too strategically, the rest of the group, with other vested interests, would challenge the information being provided and develop a consensus on more realistic assumptions. Finally, the working group presented its assumptions on the potential for generation and adoption of technologies to the larger group of major research stakeholders, including input and processing industry representatives, as well as farmers, for review and in some cases modification. This process of client review placed further pressure on working group members to provide realistic estimates. Technology generation and adoption parameters are presented in table 4.

Overall, the moist transitional zone shows the highest potential for increasing maize yields through varietal development. Specifically, KARI scientists felt there was a strong likelihood they can develop varieties for this zone with growing periods
that fall between the currently available 500 and 600 series maize varieties. These varieties would ease constraints that occur when harvesting maize grown during the first rains while attempting to plant a new crop to capitalize on the second rains. Removing this constraint is expected to result in large (32 percent overall) yield gains and the new varieties are thought likely to be widely adopted by farmers (80 percent, six years after release). In contrast, breeders seeking to develop new varieties suitable for the dry mid-altitude zone face a multitude of serious constraints. Hence, the probability of successfully generating a variety with high expected yield gains is low.\textsuperscript{12} The last zone worth noting is the high tropics. Given the concentration of past efforts in this zone, the working group felt there was limited scope for dramatic improvement upon current yields. The research focus in this area is on mitigating yield declines in current varieties due to pest and disease pressures. Further, given the familiarity of farmers with the use of hybrids in this zone, it was felt that a significant proportion of farmers would be willing to replace current varieties with varieties that have enhanced pest and disease resistance despite the prospects of comparatively modest yield gains. The results from this structured elicitation exercise also served to highlight the lengthy lags involved in generating, disseminating, and adopting improved varieties. In none of the zones are varieties expected to enter the declining phase of the adoption profile within the 30 years encompassed by the simulation model.

Maize policies and market structure

The role of the state in Kenyan maize markets is controversial. The National Cereal Produce Board (NCPB) has traditionally sought to control many aspects of both the internal and external marketing of maize in Kenya.\textsuperscript{13} Internal restrictions on maize marketing have recently been lifted, however the NCPB still maintains an official fixed pan-territorial producer price for maize. This policy has resulted in a huge accumulated debt, to the point where NCPB debts reportedly account for an estimated 20 percent of the total government deficit. Gradually, the burden of this debt and internal as well as external calls for market liberalization have resulted in a commitment to reduce the role of the board to a holder of strategic reserves for price stabilization. Ideally, the board will participate in maize markets only to maintain
prices within a band determined by import and export parity prices. However, high
transaction costs related to marketing maize suggest this band is extremely wide in a
number of areas of the country.

The magnitude of transaction costs accompanying inter-zonal trade were
empirically estimated using 1992 and 1993 Central Bureau of Statistics monthly
retail maize prices in more than 30 markets across Kenya along with Ministry of
Agriculture Market Information Branch (MIB) estimates of retail prices for bags of
maize in major markets for the period 1992-94. Markets were spatially referenced
and Thiessen polygons were constructed to allocate all area within Kenya to the
nearest market (Eastman 1990). Area-weighted, mean monthly prices of maize in
each zone were then calculated along with monthly prices for the capital city of
Nairobi.\textsuperscript{14} The estimated mean price and the price wedge for each zone relative to
Nairobi are given in table 5 for a metric ton of maize in December 1994 prices.

The low tropics has the highest priced maize reflecting the high cost of
transporting the crop to this zone from surplus regions in the western parts of
Kenya.\textsuperscript{15} The average price in the dry mid-altitude zone is also higher than the
Nairobi price, although the difference is not statistically significant. By contrast, the
moist mid-altitude, dry transitional, moist transitional, and high tropics zones all
have lower prices than Nairobi, with the difference being statistically significant in
the moist mid-altitude and dry transitional zones. The price wedges are assumed to
reflect the real transport and other miscellaneous costs of moving maize between
surplus zones and Nairobi. In our model, these cross-zone wedges were held
constant in absolute terms as prices rise and fall with research-induced shifts in
supply and other exogenous influences on the supply and demand for maize in
specific zones.

Market structure will also determine the nature of the shifts in the supply and
demand curves that have important consequences for the magnitude, and particularly
the distribution of research benefits between producers and consumers. In the
absence of contrary information, supply and demand curves are assumed linear and
to shift in a parallel fashion. We set the actual slopes of the curves based on the
estimate a long-run supply elasticity for maize in Kenya of 0.68. This estimate is
close to the median of previous estimates of long-run supply elasticities for cereal
grains and was taken to be representative of the relevant elasticity for all zones in this
study.\textsuperscript{16}

Several studies in Kenya have also estimated demand elasticities for maize.
Bezuneh, Deaton, and Norton (1988) estimated an own-price demand elasticity for
maize and beans of -1.19 as part of an almost ideal demand system for rural
households in Baringo district. Jayne, Lupi, and Mukumbu report own-price
elasticities of -1.41 and -0.11 for sifted and whole maize flour respectively for urban
Nairobi. Finally, Dorosh, delNinno, and Sahn (1994) estimate an own-price
elasticity of -0.826 in almost ideal demand system for a similar white maize based
consumption system in Mozambique. In line with the range of these estimates, a
demand elasticity of -1.0 is specified for all zones in the study.

The historical evolution of Kenya’s external trade policy is as complex as the
country’s internal marketing policies. Several factors shape the potential future
structure of maize markets. First, white maize is a preferred staple over yellow
maize. International white maize markets are thin, but research suggests they show
only marginally higher price variability than yellow maize markets (Timmer 1987).
Second, the erratic policy environment in Kenya has hindered the development of
efficient import markets. Thus transactions costs remain high.\textsuperscript{17}

The future structure of Kenyan maize markets will largely depend on the
government’s commitment to either maintain barriers to maize imports and promote
maize self-sufficiency or liberalize external trade and assist the private sector to
lower the transactions costs associated with the importation and distribution of
maize. In order to highlight the policy trade-offs faced under these alternative
strategies and their potential impacts on agricultural research benefits, three external
trade scenarios were included in the simulation results.

1. Closed economy: A combination of high transactions costs and public policies
   that effectively close Kenyan markets to external trade over the next 30 years and
   all demand increases must be met through increased internal production.

2. Small open economy: Kenya is assumed to be a price taker in world white maize
markets (i.e., the rest-of-world supply elasticity for Kenya approaches infinity) wherein all excess domestic demand over the next 30 years is met at the present Nairobi price.

3. Large open economy: Kenya represents a significant share of regional trade in white maize markets and are expected to meet future demand through trade in the region. In this scenario the rest-of-world share of maize production is specified as the residual share of East and Southern Africa maize production that totals 8.856 million tones (CIMMYT 1994). The rest-of-world supply and demand elasticities are set equal to those within Kenya.

SIMULATION RESULTS

Expected total benefits from maize varietal development research are presented in table 6 for the closed, small-open, and large-open economy scenarios. Focusing on the closed economy case, the results suggest that the total present value of benefits (in 1994 prices) from maize varietal development could be quite large (KSH52 billion). Further, the majority of these benefits accrue to households in the moist transitional zone, reflecting the large production base and the high potential for generating and adopting improved varieties with significant yield gain potential in this area. The benefits from research from just this zone, more than justify the projected costs of the total maize research program. The dry transitional zone records the second highest overall returns. Although it is highly likely that new varieties could be developed that result in significant yield gains for this part of the country, these per acre productivity improvements are applied to a reasonably small production base. While all zones benefit from the effects of research, the gains in the remaining four zones occur solely in response to the pecuniary spillover effects of R&D (that affect prices in regions not subject to technological changes) rather than the local or spillover effects of research. Successful research causes the supply curve to shift down in the aggregate, relative to the situation without research, thereby lowering prices and leading to gains to consumers of maize. In the low tropics, dry mid-altitude, moist mid-altitude, and high tropics zones, when the external market for maize is closed the loss to producers from lower prices
overshadows the unit-cost reductions they realize from research, which lowers producer surplus in this zone.

The distribution of total research benefits between zones remains unchanged under the small, open and large, open economy scenarios. However, the magnitude of benefits and the distribution between consumers and producers changes. In the small-open economy case, domestic maize prices are fixed at world market prices so Kenyan consumers get no gains from research. By contrast, producer benefits from research are larger in the small-economy compared with the closed-economy case because savings in per unit production costs are not offset by a drop in prices received by farmers. The total benefits to Kenya from varietal development research are slightly less in the small-open economy situation compared with the closed economy case. The results from the large-open economy scenario are intermediate to the closed and small-open economy cases. Changes in benefits to Kenya are muted by the effects of external markets. Compared with the closed-economy case, both consumers and producers receive smaller benefits from research.

The terminal market conditions after simulating the cumulative effects of maize research for 30 years are presented in table 7. The “with research” scenario reveals that the terminal market conditions are radically different depending on the type of economy used as a basis for the simulation. With a closed economy, prices are expected to rise by 39 percent and the quantity supplied by 49 percent if population driven increases in domestic demand were to be satisfied solely from local sources. Imports, by definition of the economy type, remain at zero. With the small-open economy assumptions, prices remain unchanged over the entire length of the simulation run. The quantity of maize supplied from domestic sources increases by 21 percent in response to the effects of research and the expansion of area sown to maize, while imports rise to 71 percent of domestic supply. Once again, the results from the large-open economy case fall within the range indicated by the closed and large-open economy simulations.

Comparing the results from the with and without research cases highlights the role of research in dampening the rise of maize prices that would occur in a closed economy that was absent technological changes. In the small open economy case,
benefits are mainly manifest through reduced imports. Further, examining the relative impact of sources of change suggests research has a greater effect than area expansion in moderating future prices and the quantity of imports. Yet it is population growth and its effect on demand that is the major determinant of future market conditions for maize in Kenya. If Kenya’s population ceased to grow, the results from the closed economy model indicate that a 12 percent decrease in maize prices and 13 percent increase in the quantity of maize supply by Kenyan farmers would come as a consequence of R&D and area expansion effects. In an open economy situation, Kenya would actually become an exporter of maize.

CONCLUSION

The simulation results presented in this paper make it apparent that the productivity gains from new crop varieties stemming generated through maize improvement research are insufficient to enable Kenya to maintain both self sufficiency in maize and current market prices. This result holds even when the effects of expanding the area sown to maize are factored into the analysis. A political choice will be needed between these conflicting objectives. Our results do not however imply, that the payoff to maize research is likely to be low. Rather, they highlight the challenges facing the Kenyan research system in servicing an agricultural sector that is subject to a rapid growth in population and a changing policy environment.

The Kenyan maize economy (and the agricultural sector more generally) appears in need of some serious policy reforms. We have not sought to model the potential path of this transformation; the agricultural sector is far more flexible than this model could hope to capture. It is likely that a conducive policy environment would stimulate increased input use, continued substitution for high value crops such as horticultural products, and probably even movement into vertical processing industries. However, the generation and transfer of new agricultural technologies in conjunction with a liberalized policy environment will be critical components of this potential transformation.

Investments in information will be essential for the effective implementation
of these policy reforms. Some of the critical environmental and policy variables for sector transformation have been highlighted in this paper, based on information from a number of sources. The collection and analysis of these information sets requires a significant investment by NARS, particularly those with weak socioeconomics capacity. The challenge remains, particularly in sub-Saharan Africa, to not only develop data which build the basis for a better picture of the future agricultural environment and the potential role for research within that environment, but to use the results in resource allocation and policy decisions.
REFERENCES


NOTES

1. Scoring models rank potential research impact based on standardized scores attached to a several weighted research objectives. As an indicator of its prevalence of use, nine of ten national research institutes in the Association for Strengthening Agricultural Research in East and Central Africa have set cross-commodity research priorities with scoring models.

2. The priority setting process highlighted in the paper was developed with the Kenya Agricultural Research Institute (KARI). Parameters generated by the Maize Program for plant breeding research are used as an example in the paper, however a similar process has been completed with ten of seventeen commodity programs in the institute.

3. In the last decade National Cereals and Produce Board efforts at price stabilization have grown to account for about twenty percent of the national debt of Kenya. Argwings-Kadheh (1995).


5. The magnitude of the supply elasticity will depend in part on Kenya’s ability to influence the world price of white maize.

6. For a description of the data used to specify maize specific agroclimatic zones see Hassan (1996).

7. Detailed discussion of the KMDBP survey and data is found in Hassan (1996).

8. No household level maize consumption figures existed for the urban centers of Nairobi and Mombassa, or the districts in the North Eastern Province. National household average levels were assumed to represent the pattern of consumption in these areas.

9. Arguably, the observed negative growth rates in the other zones are due to the substitution from maize to other crops in the high potential areas. Thus, a zero rate of area expansion may represent a best case scenario, in terms of the maintenance of maize production.

10. The KMDBP collected comprehensive base-line information on maize farmers’ practices and technology adoption patterns from a geo-referenced survey of 1400 farmers across 30 districts in the country, including current and historical adoption patterns for improved maize varieties (Hassan 1996).


12. It is commonly felt that the rate of progress in varietal development decreases at least proportionally with the number of traits emphasized. Byerlee 1996.

13. De-facto, the private sector has always maintained a majority share in maize marketing activities, albeit under stifling regulations.

14. The number of markets was insufficient to calculate a monthly zone average for the non-maize growing regions outside Nairobi.

15. Since maize imports were officially controlled, the price is not reflective of import prices at Mombassa port.

16. Rao (1989), in a review of empirical supply elasticity estimates, finds long run estimates generally lie between 0.3 and 1.2.

17. Based on April 1992 prices, Njoro (1992) calculated a Nairobi import parity price of 614 Ksh per 90 Kg. bag and export parity price of 195 Ksh per bag. Domestic producer prices ranged from 300 to 400 Ksh during the same period.
<table>
<thead>
<tr>
<th>Zone</th>
<th>Elevation (meters)</th>
<th>Rainfall (mm)</th>
<th>Temperature (degrees Celsius)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Tropics</td>
<td>0-800</td>
<td>500-1000</td>
<td>&lt;30° Ave. Max. and &gt;20° Ave. Min. for March-August</td>
</tr>
<tr>
<td>Dry - Mid. Altitude</td>
<td>400-1400</td>
<td>250-500</td>
<td>&lt;30° Ave. Max. for March-August</td>
</tr>
<tr>
<td>Moist - Mid. Altitude</td>
<td>1000-1400</td>
<td>&gt;500</td>
<td>NA</td>
</tr>
<tr>
<td>Dry - Transitional</td>
<td>1400-1800</td>
<td>300-500</td>
<td>NA</td>
</tr>
<tr>
<td>Moist - Transitional</td>
<td>1400-2000</td>
<td>&gt;500</td>
<td>&gt;11° Ave. Min. for March-August</td>
</tr>
<tr>
<td>High Tropics</td>
<td>1800-2500</td>
<td>&gt;500</td>
<td>&gt;7° Ave. Min. for March-August</td>
</tr>
</tbody>
</table>

NA: Not Applicable
Table 2. Maize Supply and Demand by Agroclimatic Zone

<table>
<thead>
<tr>
<th>Zone</th>
<th>Production (metric tons)</th>
<th>Consumption (metric tons)</th>
<th>Net Surplus (metric tons)</th>
<th>Population (1989)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Tropics</td>
<td>53,000</td>
<td>251,000</td>
<td>-198,000</td>
<td>1,428,036</td>
</tr>
<tr>
<td>Dry MAT</td>
<td>162,000</td>
<td>316,000</td>
<td>-154,000</td>
<td>3,526,531</td>
</tr>
<tr>
<td>Moist MAT</td>
<td>232,000</td>
<td>387,000</td>
<td>-155,000</td>
<td>3,362,371</td>
</tr>
<tr>
<td>Dry TNZ</td>
<td>76,000</td>
<td>122,000</td>
<td>-46,000</td>
<td>1,257,568</td>
</tr>
<tr>
<td>Moist TNZ</td>
<td>1,234,000</td>
<td>621,000</td>
<td>613,000</td>
<td>5,814,631</td>
</tr>
<tr>
<td>High Tropics</td>
<td>909,000</td>
<td>427,000</td>
<td>482,000</td>
<td>3,988,433</td>
</tr>
<tr>
<td>Non-Urban Rest of Kenya*</td>
<td>0</td>
<td>311,000</td>
<td>-311,000</td>
<td>741,496</td>
</tr>
<tr>
<td>Nairobi</td>
<td>0</td>
<td>231,000</td>
<td>-231,000</td>
<td>1,324,576</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,666,000</strong></td>
<td><strong>2,666,000</strong></td>
<td><strong>0</strong></td>
<td><strong>21,443,636</strong></td>
</tr>
</tbody>
</table>


* These are districts in the non-maize growing regions, primarily in the arid Northern Province.
<table>
<thead>
<tr>
<th></th>
<th>Population Growth</th>
<th></th>
<th>Area Expansion</th>
<th>Projected Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1979-1989</td>
<td>Projected Rate</td>
<td>1987-1991</td>
<td>Rate</td>
</tr>
<tr>
<td></td>
<td>percentage</td>
<td>(-25%)</td>
<td>percentage</td>
<td>percentage</td>
</tr>
<tr>
<td>Low Tropic</td>
<td>3.06</td>
<td>2.29</td>
<td>-0.86</td>
<td>0</td>
</tr>
<tr>
<td>Dry MAT</td>
<td>3.40</td>
<td>2.55</td>
<td>3.12</td>
<td>3.12 to 0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Moist MAT</td>
<td>3.07</td>
<td>2.30</td>
<td>-3.84</td>
<td>0</td>
</tr>
<tr>
<td>Dry TNZ</td>
<td>3.89</td>
<td>2.92</td>
<td>6.36</td>
<td>6.36 to 0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Moist TNZ</td>
<td>3.25</td>
<td>2.44</td>
<td>-1.37</td>
<td>0</td>
</tr>
<tr>
<td>High Tropics</td>
<td>3.69</td>
<td>2.77</td>
<td>-0.94</td>
<td>0</td>
</tr>
<tr>
<td>Non-Urban Rest of Kenya</td>
<td>1.24</td>
<td>0.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nairobi</td>
<td>4.70</td>
<td>3.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate</td>
<td>3.36</td>
<td>2.52</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


<sup>a</sup> Rate of area expansion is modeled as linearly decreasing from current rate to zero over 30 years.
## Table 4. Technology Generation and Adoption Potentials

<table>
<thead>
<tr>
<th>Yield Gains From Varietal Development</th>
<th>Net yield gains</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td></td>
<td>percent</td>
</tr>
<tr>
<td>Low Tropics</td>
<td>4.20</td>
</tr>
<tr>
<td>Dry MAT</td>
<td>5.00</td>
</tr>
<tr>
<td>Moist MAT</td>
<td>3.75</td>
</tr>
<tr>
<td>Dry TNZ</td>
<td>10.00</td>
</tr>
<tr>
<td>Moist TNZ</td>
<td>15.00</td>
</tr>
<tr>
<td>High Tropics</td>
<td>5.00</td>
</tr>
</tbody>
</table>

### Adoption Profiles for Varietal Development

<table>
<thead>
<tr>
<th></th>
<th>Research &amp; Development Lag</th>
<th>Maximum Adoption</th>
<th>Start of Dis- adoption</th>
<th>Complete Dis-adoption</th>
<th>Maximum Adoption Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Years)</td>
<td>(Years)</td>
<td>(Years)</td>
<td>(Years)</td>
<td>percent</td>
</tr>
<tr>
<td>Low Tropics</td>
<td>10</td>
<td>20</td>
<td>40</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Dry MAT</td>
<td>10</td>
<td>18</td>
<td>35</td>
<td>42</td>
<td>20</td>
</tr>
<tr>
<td>Moist MAT</td>
<td>10</td>
<td>17</td>
<td>32</td>
<td>39</td>
<td>60</td>
</tr>
<tr>
<td>Dry TNZ</td>
<td>10</td>
<td>15</td>
<td>30</td>
<td>35</td>
<td>60</td>
</tr>
<tr>
<td>Moist TNZ</td>
<td>10</td>
<td>16</td>
<td>36</td>
<td>42</td>
<td>80</td>
</tr>
<tr>
<td>High Tropics</td>
<td>10</td>
<td>20</td>
<td>32</td>
<td>37</td>
<td>40</td>
</tr>
</tbody>
</table>

\(^a\) Pr(K\(_i\) > K\(_i\)^\text{d}), \(^b\) \text{E}[K\(_i\) | K\(_i\) > K\(_i\)^\text{d}]\).
<table>
<thead>
<tr>
<th>Zone</th>
<th>Mean</th>
<th>Nairobi wedge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Tropics</td>
<td>15,070</td>
<td>2,030</td>
</tr>
<tr>
<td>Dry MAT</td>
<td>13,400</td>
<td>360</td>
</tr>
<tr>
<td>Moist MAT</td>
<td>12,180</td>
<td>-860</td>
</tr>
<tr>
<td>Dry TNZ</td>
<td>12,590</td>
<td>-550</td>
</tr>
<tr>
<td>Moist TNZ</td>
<td>12,540</td>
<td>-500</td>
</tr>
<tr>
<td>High Tropics</td>
<td>12,930</td>
<td>-110</td>
</tr>
<tr>
<td>Nairobi</td>
<td>13,040</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Note: Based on 1992 - 1994 series adjusted to December 1994 prices. Paired t-Tests showed that mean is statistically significantly different at 5% level from: a Low Tropics, b Dry MAT, c Moist MAT, d Dry TNZ, e Moist TNZ, f High Tropics, and g Nairobi.
### Table 6. Potential Benefits from Maize Improvement Research:
(Million Kenya Shilling)

<table>
<thead>
<tr>
<th>Market structure:</th>
<th>Low Tropics</th>
<th>Dry MAT</th>
<th>Moist MAT</th>
<th>Dry TNZ</th>
<th>Moist TNZ</th>
<th>High Tropics</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Closed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumer surplus</td>
<td>2,027</td>
<td>2,630</td>
<td>2,966</td>
<td>1,086</td>
<td>4,951</td>
<td>3,703</td>
<td>21,518</td>
</tr>
<tr>
<td>Producer surplus</td>
<td>-233</td>
<td>-1,598</td>
<td>-1,049</td>
<td>1,434</td>
<td>34,629</td>
<td>-2,485</td>
<td>30,696</td>
</tr>
<tr>
<td>Total</td>
<td>1,794</td>
<td>1,031</td>
<td>1,917</td>
<td>2,520</td>
<td>39,580</td>
<td>1,218</td>
<td>52,215</td>
</tr>
<tr>
<td><strong>Small open</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumer surplus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Producer surplus</td>
<td>125</td>
<td>71</td>
<td>558</td>
<td>2,354</td>
<td>38,258</td>
<td>3,546</td>
<td>44,915</td>
</tr>
<tr>
<td>Total</td>
<td>125</td>
<td>71</td>
<td>558</td>
<td>2,354</td>
<td>38,258</td>
<td>3,546</td>
<td>44,915</td>
</tr>
<tr>
<td><strong>Large open</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumer surplus</td>
<td>550</td>
<td>727</td>
<td>840</td>
<td>302</td>
<td>1,390</td>
<td>1,027</td>
<td>5,998</td>
</tr>
<tr>
<td>Producer surplus</td>
<td>51</td>
<td>-284</td>
<td>232</td>
<td>2,167</td>
<td>37,864</td>
<td>2,329</td>
<td>42,361</td>
</tr>
<tr>
<td>Total</td>
<td>602</td>
<td>443</td>
<td>1,073</td>
<td>2,469</td>
<td>39,254</td>
<td>3,357</td>
<td>48,359</td>
</tr>
</tbody>
</table>

*Includes consumer surplus measures for “Nairobi” and “Rest of Kenya”. Benefits to “Rest of World” in open economy cases are not included.*
Table 7. Simulated Changes in Economic Aspects of Maize Markets over 30 Years

<table>
<thead>
<tr>
<th>Economic Aspect</th>
<th>Closed (percent)</th>
<th>Small Open (percent)</th>
<th>Large Open (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With research</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in Nairobi price</td>
<td>+39</td>
<td>0</td>
<td>+11</td>
</tr>
<tr>
<td>Change in internal supply</td>
<td>+49</td>
<td>+21</td>
<td>+29</td>
</tr>
<tr>
<td>Imports as percent of internal supply</td>
<td>0</td>
<td>+71</td>
<td>+48</td>
</tr>
<tr>
<td>No research</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in Nairobi price</td>
<td>+47.1</td>
<td>0</td>
<td>+13</td>
</tr>
<tr>
<td>Change in internal supply</td>
<td>+41.1</td>
<td>+8</td>
<td>+17</td>
</tr>
<tr>
<td>Imports as percent of internal supply</td>
<td>0</td>
<td>+93</td>
<td>+62</td>
</tr>
<tr>
<td>Research, no area expansion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in Nairobi price</td>
<td>+42</td>
<td>+0</td>
<td>+12</td>
</tr>
<tr>
<td>Change in internal supply</td>
<td>+43</td>
<td>+14</td>
<td>+22</td>
</tr>
<tr>
<td>Imports as percent of internal supply</td>
<td>0</td>
<td>+83</td>
<td>+55</td>
</tr>
<tr>
<td>Research, no population growth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in Nairobi price</td>
<td>-12</td>
<td>0</td>
<td>-3</td>
</tr>
<tr>
<td>Change in internal supply</td>
<td>+13</td>
<td>+21</td>
<td>+19</td>
</tr>
<tr>
<td>Imports as percent of internal supply</td>
<td>0</td>
<td>-17</td>
<td>-14</td>
</tr>
</tbody>
</table>

Note: No dis-adoption of varieties is expected within the 30-year evaluation horizon.
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Global Agricultural Science Policy for the Twenty-First Century

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26-28 August 1996

Melbourne, Australia
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