The Welfare Effects of Maize Technologies in Marginal and High-Potential Regions of Kenya

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A long-standing debate within the CGIAR system revolves around the effects on various populations (particularly the poor) of different allocations of research effort between marginal and favored production environments. Some argue that there has been systematic under-investment in marginal production environments — to the detriment of the large group of impoverished people within those areas (Fan and Hazell, 1999; Hazell and 1996). Others counter that investment in marginal areas historically has been low *precisely because* the returns to those investments are low, and that diverting research resources away from favored production environments would do more harm than good overall (Coxhead and Warr, 1991; Renkow, 2000).

In Kenya, this debate is critically important for several reasons. First, agriculture is the dominant sector in the economy, accounting for 28-30 percent of GDP. Second, the country has one of the fastest growing populations in the world which puts considerable pressure on the arable 20 percent of total land area to produce sufficient food. The consequence of this has been reduced fallow periods, fewer crop rotation options, and a loss of soil fertility and land productivity. Third, and partly due to the second point, there has been a notable out-migration from the high-potential to low-potential agro-ecological zones, with an accompanying increase in the importance of agricultural production on less-favored lands. This transformation of the spatial distribution of production has serious implications for both agricultural research and the environment. Finally, Kenya's economy has been on the downturn for the past two decades, resulting in a severe reduction in available resources for agriculture research.

Maize is by far the most important crop grown in Kenya, both in terms its contribution to total value added in agriculture and its position as the dominant staple food consumed by the great majority of Kenyans. As such, any agriculture-led development strategy for Kenya must focus on enhancing maize productivity and the well-being of maize producers and consumers.

In this regard, Kenya is fortunate to possess one of the preeminent national agricultural research systems in all of Africa – the Kenyan Agricultural Research Institute (KARI). KARI has a successful track record and has developed a number of promising technologies for a variety of agroecological zones. Past increases in maize production were fueled by the development of high yielding varieties, crop management technologies, and in area under maize cultivation. While maize productivity growth has declined since the mid-1970s, a wide gap separates experiment station yields from those achieved in farmers' fields. This indicates that significant productivity gain could be achieved through better targeting and promotion for adoption of improved technologies.

Recent setbacks in the performance of the agricultural sector – due to bad weather, on-again off-again policy reform (and political mismanagement thereof), and institutional shakeups – have caused many of the fruits of KARI's agricultural research to go "unharvested." Nonetheless, the technologies remaining on the shelf have significant potential for increasing output. These packages embody a mix of plant genetic and crop management innovations.

An interesting aspect of this delay in the diffusion of technologies currently on the shelf is that it facilitates *ex ante* evaluation of the relative impacts of the zone-specific technology packages. The research summarized in this paper embodies such an *ex ante* evaluation. We employ a multi-market model of Kenyan maize production to assesses the potential impact of improved maize technology on the incomes of both rural and urban households in Kenya. We analyze the likely impacts on various household types of the diffusion of improved maize varieties and crop management technologies that are currently available.

In our model the direct effects of technical change are based on assessments made by experts in the Kenyan agricultural research system. The model computes the indirect effects that are transmitted through product and factor markets via endogenous changes in quantities and prices. The model is disaggregated into six distinct agro-ecological production zones. This allows us to investigate alternative technology adoption scenarios – scenarios in which diffusion is confined to either favored or marginal production environments versus scenarios in which technical change is assumed to take place in all areas.

Our results suggest a few generalizations are available regarding the potential welfare effects of widespread diffusion of maize technologies currently on the shelf in Kenya. First, maize technologies that have been developed for favored agroecological zones are likely to have more profound aggregate impacts on maize production, and thus will lead to greater reductions in maize prices (if maize prices are flexible) or import demand (if prices are controlled). Second, diffusion of technologies in favored areas is likely to have substantially greater positive impacts on aggregate real incomes. Third, the way in which the maize market clears has important ramifications for both the magnitude and distribution of gains and losses from various scenarios of technology adoption: when maize prices are exogenously determined, aggregate income increases are generally somewhat greater and the number of household types that suffer real income losses is smaller than when prices are endogenously determined. A notable exception to this latter point is urban households, for whom welfare increases when prices are endogenous (and is unchanged when prices are exogenous).

The paper is laid out as follows. In the next section, we describe the multi-market model on which our empirical analysis is based. Following this, we discuss the data and assumptions used to implement the model. We then present our empirical results. Discussion of these results is found in the paper's final section.

Analytical Framework

The basis for our empirical analysis is a multi-market model of maize production in Kenya (Karanja, forthcoming). The model is very similar in spirit to one developed by Renkow (1993) for analyzing the differential regional impacts of wheat technologies in Pakistan. It is a much larger model, though, insofar as it considers agricultural production across a much more disaggregated set of agroecological zones.

The Kenya multi-market model features a system of equations specifying functional relationships characterizing the economic behavior of two types of rural households (small farms and large farms) in each of Kenya's six agroecological zones, as well as urban households. Household behavioral equations are specified for agricultural production activities (output supply and input demand functions), consumption demand, and household labor supply. These are combined with identities decomposing aggregate production, consumption, and labor supply (into regional sub-components), agricultural profits (the value of production less input costs), and household income (into farm profits, agricultural labor income, and other exogenous income).

The model considers two crops (maize and “other” crops), two production inputs (labor and fertilizer), two consumption items (maize and “other” goods) for each type of household. Markets for maize and labor are assumed to clear nationally. The model solves for the equilibrium agricultural wage rate by equating aggregate (national) supply and demand for labor. For maize, two variant market clearing conditions are employed. The first is an “open economy” (fixed price) scenario in which maize price as assumed to be exogenously determined (e.g., by the world market or via government price policy); in this case, maize imports are endogenously determined. The second variant is a “closed economy” scenario in which the maize price is assumed to be determined by the intersection of aggregate demand and supply (with imports being exogenously determined).

Exogenous variables in the system include all prices (other than those for maize and labor), population growth, and a vector of technical change variables that relate specific technology packages to shifts in maize supply and input demand. Endogenous variables include all agricultural outputs and input demands, consumption demands, profits, incomes, household-specific price indices, the price of maize (or maize imports) and the agricultural wage rate.

The model is solved in log-differential (rate-of-change) form such that changes in the endogenous variables depend on changes in exogenous variables. Formally, the model can be expressed as $\mathbf{HU} = \mathbf{K}$, where $\mathbf{U}$ is an $n \times 1$ vector of proportional changes in endogenous variables, $\mathbf{K}$ is an $n \times 1$ vector of proportional changes in exogenous variables, and $\mathbf{H}$ is an $n \times n$ matrix of parameters (elasticities and shares). Inverting the $\mathbf{H}$ matrix and pre-multiplying both sides of the equation allowed us to simulate the changes in endogenous variables that would result from shocks to the system (in the form of changes in a subset of exogenous variables). In particular, we used the model to investigate how prices, quantities, farm profits, and household income would change in response to various production “shocks” resulting from alternative scenarios of diffusion of maize production technology packages that are currently available.

Implementation

Our model considers small and large farm households in six agroecological zones of Kenya (Table 1). Four of these areas (Lowlands, Dry Midaltitude, Moist Midaltitude, and Dry Transition) are characterized by relatively difficult agronomic conditions, low maize yields, and low levels of marketed surpluses of maize (Tables 2 and 3). We will refer to these areas as marginal agroecological zones. On the other hand, two areas (Moist Transition and Highlands) enjoy very good agronomic conditions, have much higher maize yields and a significantly greater degree of commercialization. We will refer to these areas as favored agroecological zones. Kenya's rural population is more or less evenly split between the two, with 1.6 million agricultural households in the marginal zones and 1.8 million households in the favored zones.

Implementing the multi-market model required assembling a prodigious amount of data. Three types of data were required: (a) share parameters identifying the relative importance of various sub-components of households' production, consumption, agricultural profits, and income; (b) estimates of supply and demand elasticities governing household response to changes in prices and income; and (c) estimates of likely changes in key exogenous variables (notably, population growth rates and technology shifters).

Share Parameters

The share parameters used in this were computed from data collected as part of the Kenya Maize Impact Study (KMIS). The KMIS collected household level information from a sample of 426 farmers located in six maize agro-climatic zones in Kenya, as well as village level information for the 30 villages in which respondents dwelled (Karanja, forthcoming). The household and village surveys were conducted concurrently between June and October 1999.[1]

Table 4 presents the key share parameters used to initialize the multi-market model. These shares go a long way in providing an understanding of the empirical results. Beginning with regional maize production shares, it is clear that the two favored agroecological zones dominate national maize output. Taken together these two regions account for over two-thirds of maize production. Large farms play a particularly important role in the Moist Transition zone output; in nearly all other zones smallholders account for equal or larger shares of zonal maize output than large farms. Clearly, factors that enhance maize yields in more important maize production areas will have greater impacts on aggregate maize supply and, if the national maize market is closed, the price of maize.

All else equal, an increase in the profitability maize production will affect more strongly those households for whom profits from maize production represent a large share of household income. The share data reported in Table 4 indicate that the contribution of maize to farm profits varies widely across zones, as does the importance of farming income to total household income. Taken together these data indicate that profits from maize production are a particularly important proportion of total household income for both small and large farm households in the favored zones as well as in the (marginal) Moist Midaltitude zone. Maize profits appear to be a relatively insignificant (<5%) fraction of total household income for two groups – small farms in the Lowlands zone and large farms in the Dry Transition zone.

In addition to farm profits, rural households in Kenya also obtain a sizable fraction of household income from returns to agricultural labor. Thus, factors that affect agricultural wage rates (e.g., shifts in labor demand attributable to diffusion of new technologies) may have important impacts on household well being. As was the case for profit shares, the labor income shares vary widely, both across and within

[1]The sampling frame of the KMIS was a subset of a much larger household survey conducted as part of the 1994 Kenya Maize Data Base project. That project used GIS techniques to design a spatial sampling frame for a national survey of 1407 Kenyan maize farmers (see Hassan, Lynam, and Okoth, 1998 for details). For the KMIS,

agroecological zones. In all zones, agricultural labor earnings are more important for small farm households than for large farm households. This is particularly evident in the two favored zones and the (marginal) Moist Midaltitude zone.

Finally, to the extent that shifts in maize supply lead to lower maize prices, the positive impact on real incomes of maize technology diffusion will be greater the larger are household expenditure shares. Expenditure shares reported in Table 4 indicate considerable heterogeneity across household types, ranging from a very low value for large farm households in the Dry Midaltitude zone (2.6%) to very high values (approaching 50%) for large farms in the Lowlands and Dry Transition zones.

Elasticities

Elasticities were taken from a variety of sources. Zone specific output supply and input demand were available from Munyi. Labor supply elasticities used were those reported in Pitt and Sumodiningrat. Consumption demand elasticities were adapted from Renkow's (1991) work in Pakistan.

Technological Change Shifters

Our estimates of maize supply and input demand shifters associated with on-the-shelf technology packages were those reported by Mills, Hassan, and Mwangi (1995). Technology generated yield improvements were envisaged to consist of two distinct processes: (1) technology development; and (2) technology adoption. The technology development process was modeled as a triangular distribution of possible outcomes (net yield gains or losses) adjusted for incremental input use and measured over a 30-year period, but in the case of this study, a 15-year period (Mills, Hassan, and Mwangi, 1998). The expected percentage net yield gain is then estimated from two parameters from the distribution outcomes: (1) the probability of exceeding the net yield gain dissemination threshold; and (2) the expected net increase conditional on the dissemination threshold being exceeded. The expected net yield improvement was thus estimated conditional upon exceeding the adoption threshold. These parameters were derived

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the proportional distribution of the farmers between different zones was determined by the relative importance of maize in each zone, logistical considerations and available research funds.

from expert information generated by a stakeholder committee and adapted by the Kenya Agricultural Research Institute.

The research impact also depends on the rate and extent of technology adoption, thereby necessitating construction of a research adoption profile. A linear approximation of the adoption profile was used, with the profile typically including a research development lag, an initially increasing adoption rate, an adoption plateau where most targeted farmers have been exposed to the technology and decide whether to adopt or not, and a declining adoption rate as the technology becomes obsolete. When combined, these determine the speed and frequency of technology adoption. Finally, the adjusted net yield gain is the product of the probability of dissemination and the conditional expected net yield gain.

Table 5 presents the net yield gains and input demand increases associated with zone-specific technology packages considered. On average, the net yield gains ranged from 7% in the Lowlands zone to 29.7% in the Moist Transition zone. Surprisingly, the (favored) Highland zone had a low projected net yield gain of only 9% traceable to a relatively low expected impact from breeding and crop management compared to the other favored zone (Moist Transition).

In general, a higher percentage of projected yield improvements in marginal agroecological zones was attributed to changes in crop management practices, whereas breeding research was projected to have a relatively more important role in favored zones. Associated with this, the implications of technological change for labor demand were correspondingly higher in marginal zones.

Results

The multi-market model was used to simulate the impacts of various scenarios of technological change. Two sets of analyses were conducted, both of which assess the long-run impacts of different regional patterns of technology adoption relative to a baseline case in which no technological change occurs. The first assumes producer and consumer prices of maize are fixed; the second assumes that maize prices freely adjust to changes in domestic supply and demand conditions.

The fixed price case can be thought of as representing the situation in which the government sets both producer and consumer prices of maize in accordance with its own price policy objectives,[2] and imports are endogenously determined. In many respects, this characterization resembles the situation in the Kenyan maize market prior to it being liberalized in the mid-1990s. The flexible price (or closed economy) case can be thought of as one in which domestic maize market is liberalized with respect to internal trade. However, as modeled here, the government maintains some (potentially significant) influence in the maize market in that maize imports are exogenously determined (presumably as a part of government trade policy).

Technological Change with Fixed Maize Prices

Tables 6a, 6b, and 6c present the simulated impacts of various scenarios of technological change under fixed maize prices. The three scenarios considered include one in which diffusion of maize technologies occurs only in the marginal agroecological zones; one in which diffusion is confined to the favored agroecological zones; and one in which diffusion occurs in all zones. In all scenarios, maize price is assumed to be unchanged from the baseline.

The results indicate distinctly different impacts on real agricultural wages and aggregate output, depending on the regional pattern of technology diffusion. In all cases, agricultural wages increase due to a shift in labor demand accompanying technology adoption. However, wages are more profoundly affected in scenarios in which technology adoption occurs in the marginal zones, because marginal zone technology packages feature more labor intensive crop management technologies. In contrast, diffusion of improved technologies in favored zones has a much stronger positive impact on national maize output than scenarios in which diffusion is confined to marginal zones. As such, enhancing the productivity of favored zone maize farming holds greater potential for reducing import demand.

Changes in the farm profits of different farm types in different locations depend on two factors: whether or not the farm is an adopter, and how labor intensive maize farming is for the particular farm

[2] Alternatively, it can be thought of as the case in which prices are determined by the world market – i.e., an open

type. Of course, profits inevitably fall for non-adopters since the maize productivity stays the same but the cost of production rises (due to higher wage rates). For adopters, profits rise or fall depending on the relative balance between yield increases brought about by the new technology and higher cost of production caused by wage increases. In the favored zones, adopting households invariably enjoy higher profits, particularly in the Moist Transition zone (where output effects are very large). In the marginal zones, profits drop for large farms. Indeed, only for small farms in the Moist Midaltitude and Dry Transition zones do profit increases accompany technological change.[3]

The net impact on real household incomes of new technologies depends on changes in wages and profits engendered by adoption of those technologies and the relative importance of those two components of household income.[4] The results in Tables 6a – 6c indicate that the positive effects of wage increases on labor income generally outweigh the negative profit effects in the overall distribution of benefits and losses. In all but the Dry Transition zone, the positive impacts on labor earnings are particularly beneficial for small farm households in the "marginal zones only" scenario.

In terms of the magnitude simulated income effects of technology adoption, it is clear that the largest increases in real incomes are achieved in the (favored) Moist Transition zone. Income effects are positive for nearly all household types in the scenarios in which technological change occurs in favored zones (Tables 6b and 6c); income effects and more mixed for the scenario in which when technology adoption is confined to the marginal zones.

Technological Change with Flexible Maize Prices

Tables 7a, 7b, and 7c present the simulated impacts of various scenarios of technological change in which the price of maize varies with changes in aggregate supply. Again we consider three scenarios, one in which diffusion of maize technologies occurs only in the marginal agroecological zones; one in which

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economy case.

[3] Recall that the technology packages for marginal zones tend to be relatively more labor intensive and, with the exception of the Dry Transition zone, produce relatively smaller yield increases. These, in combination with higher wages, explain why farm profits fall.

[4] Because maize prices are exogenously determined in these scenarios, there is no change in household-specific price indices (and hence no change in real incomes for urban households).

diffusion is confined to the favored agroecological zones; and one in which diffusion occurs in all zones. In all scenarios, maize imports are held at the same level as in the baseline case.

Because the maize price falls in these scenarios, simulated impacts on profits are generally lower than in the fixed price scenarios. Since maize farming is more productive in the favored zones, the decline in the maize price is steeper for scenarios in which technological change occurs in those zones. Indeed, only in the (favored) Moist Transition zone do profits increase when technology adoption occurs in the favored zones. In the "marginal zones only" scenario, profits decline for all household types except for large farms in the Dry Transition zone.

In the flexible price scenarios, the drop in maize prices causes household-specific price indices to fall. This increases the well-being of all households, with benefits proportional to the expenditure shares of maize. Whether this positive effect (along with the positive impact of increased returns to agricultural labor) are sufficient to make up for declines in farm profitability that most households experience varies widely. In the "marginal zones only" scenario, five of eight household types in marginal zones enjoy net increases in real incomes while all (non-adopting) households in favored zones experience real income declines. In the "favored zones only" scenario, households in the (favored) Moist Transition zone enjoy real income increases, as do half of the household types in the marginal zones,[5] but real incomes decline in the (favored) Highlands zone. Finally, urban households benefit from falling maize prices in all flexible price scenarios, particularly those in which technology adoption is assumed to take place in the favored zones.

Discussion

Our results suggest a few generalizations regarding the potential welfare effects of widespread diffusion of maize technologies currently on the shelf in Kenya. First, maize technologies that have been developed for favored agroecological zones are likely to have more

[5] Note that the marginal zone households for which real income increases are relatively large – large farms in the Dry Transition zone and both small and large farms in the Lowlands zone – have the largest maize expenditure shares of all household types considered.

profound aggregate impacts on maize production, and thus will lead to greater reductions in import demand (if prices are controlled) or maize prices (if maize prices are flexible).

Second, diffusion of technologies in favored areas is likely to have substantially greater positive impacts on aggregate real incomes. This can be seen in Table 8, which presents the aggregate income effects implied by each of the six scenarios of technology diffusion considered in the previous section. These aggregate effects were computed as the sum of real income increases reported in Tables 6a – 7c, weighted by household-zone specific population shares. The figures in Table 8 clearly indicate that aggregate real income effects are substantially greater for simulations in which technology diffusion occurs in favored agroecological zones (with or without diffusion in marginal zones). This finding is consistent with other analyses comparing welfare impacts of technical change across production environments (e.g., Renkow, 1991; Coxhead and Warr, 1991).

Third, the way in which the maize market clears has important ramifications for both the magnitude and distribution of gains and losses from various scenarios of technology adoption: when maize prices are exogenously determined, aggregate income increases are generally somewhat greater and the number of household types that suffer real income losses is smaller than when prices are endogenously determined. A notable exception to this latter point is urban households, for whom welfare increases when prices are endogenous (and is unchanged when prices are exogenous). This information should be of interest to policy makers with regard to continuing debates over the liberalization of agricultural markets.

Finally, making meaningful distributional assessments will require assembling information on initial the income distribution across the various household types considered here. This will facilitate comparison with simulated posterior distributions, an activity that we defer to the very near future.

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Table 1: Basic Agro-climatic, Demographic and Maize Production Characteristics by Agroecological Zone

Variable	Marginal Agroecological Zones				Favored Agroecological Zones		
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	All Zones
Mean Altitude (mASL)	52.0	841	1254	1485	1555	2267	-
Mean Rainfall (mm):							
March-August	677.6	323.1	789.6	518.9	901.4	667.7	-
September-February	347.6	423.6	541.9	563.5	553.0	339.2	-
Total	1025.2	746.6	1331.5	1082.4	1454.4	1006.9	-
Mean Temperature (^{o}C):							
Minimum	22.5	17.7	15.8	13.5	13.6	8.1	-
Maximum	30.2	30.1	28.8	26.1	27.0	22.5	-
Major Soil Type	Luvisols	Ferralsols	Acrisols	Vertisols	Nitosols	Nitosols	-
Total Pop'n Share (%)[a]	6.47	16.46	15.25	6.13	26.80	19.10	90.22
Total # of Ag Households:							
Small Farm	112,000	469,000	639,000	153,000	992,000	628,000	2,992,000
Large Farm	24,000	107,000	62,000	30,000	107,000	88,000	418,000
Maize Production, 1992-98:							
Maize Output (MT)	39,700	245,100	377,000	136,400	1,076,400	686,100	2,560,700
Maize Area (Ha)	44,800	331,400	190,000	121,700	441,000	311,300	1,440,200
Maize Yield (MT/Ha)	0.89	0.74	1.98	1.12	2.44	2.20	1.78

a. Based on 1998 estimated population, this excludes 2.83 million people in Nairobi and Non-Urban Rest of Kenya.

*Source:*Karanja (2002)

Table 2. Maize Farm and Farmer Characteristics by Agroecological Zone

Variable	Marginal Agroecological Zones				Favored Agroecological Zones		
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	All Zones
Mean Farm Size (ha):							
• Small Farm	1.65	1.51	1.34	1.03	1.05	1.45	1.32
Large Farm	7.51	14.78	7.26	-	40.94	216.18	109.74
% Small Farms (<4 ha):	83	90	82	100	84	71	83
% Female Farmers:							
Small Farm	42	59	43	58	47	53	50
Large Farm	30	17	0	-	13	21	18
% Uneducated Farmers:							
Small Farm	45	32	17	25	23	33	29
Large Farm	70	33	38	-	19	6	23
Age of Farmer (Years):							
Small Farm	43	45	43	44	41	44	43
Large Farm	44	58	56	-	50	46	49
% Crop Area in Maize:							
Small Farm	50	62	48	69	56	61	58
Large Farm	25	15	20	-	54	25	30
Maize Planting Month:							
Small Farm	Mar/Apr	Oct/Nov	Feb/Mar	Sep/Oct	Mar/Apr	Mar/Apr	Mar/Apr
Large Farm	Mar/Apr	Oct	Feb/Mar	-	Mar/Apr	Mar/Apr	Mar/Apr
Maize Harvesting Month:							
Small Farm	Jul/Aug	Feb/Mar	Jul/Aug	Feb/Mar	Aug/Sep	Nov/Dec	Jul/Aug
Large Farm	Jul/Aug	Feb/Mar	Jul/Aug	-	Nov/Dec	Nov/Dec	Nov/Dec

Source: Kenya Maize Impact Study

Table 3. Maize Production, Consumption and Marketing by Agroecological Zone

Parameter	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	All Zones
	Marginal Agroecological Zones				Favored Agroecological Zones		
Per Capita Maize Prod. (Kg):							
• Small Farm	105	91	141	59	203	343	181
• Large Farm	128	83	208	-	9483	5952	4851
Per Cap. Maize Consump. (Kg):							
• Small Farm	101	100	124	78	122	165	120
• Large Farm	139	83	111	-	487	327	292
% Net Sellers of Maize:							
• Small Farm	14	28	38	22	49	69	41
• Large Farm	0	33	38	-	94	94	70
Proportion of Maize Sold (%):							
• Small Farm	0	12	15	12	28	31	20
• Large Farm	0	21	29	-	80	75	57
% Selling to Private Traders:							
• Small Farm	0	95	83	97	88	97	88
• Large Farm	0	100	60	-	75	68	71
Maize Selling Price, Ksh/Kg:							
• Small Farm	13.50	9.45	14.05	14.25	10.40	10.05	11.50
• Large Farm	13.80	11.55	14.30	-	9.80	10.00	11.05
Maize Purchase Price, Ksh/Kg:							
• Small Farm	18.65	14.25	17.70	17.50	13.90	14.20	15.55
• Large Farm	15.90	14.45	17.90	-	11.50	10.90	12.75

Source: Kenya Maize Impact Study

Table 4. Key Parameters Used in the Multi-Market Model

Variable	Marginal Agroecological Zones				Favored Agroecological Zones	
	Lowlands	**Dry Midaltitude**	**Moist Midaltitude**	**Dry Transition**	**Moist Transition**	**Highlands**
Maize Production Shares[a] **(% of national total)**						
• Small Farms	0.5%	3.3%	9.1%	3.9%	13.6%	16.8%
• Large Farms	0.7%	4.4%	5.8%	0.5%	27.1%	11.2%
Maize Profit Shares[b] **(% of farm profits from maize)**						
• Small Farms	6.9%	16.0%	39.6%	22.9%	34.2%	33.5%
• Large Farms	34.7%	16.0%	37.7%	9.3%	38.5%	24.2%
Farming Income Shares[b] **(% of hh income from farm profit)**						
• Small Farms	42.1%	68.8%	40.7%	57.8%	53.1%	74.8%
• Large Farms	41.4%	64.5%	82.3%	51.4%	95.3%	93.8%
Labor Income Shares[b] **(% of hh income from ag labor)**						
• Small Farms	10.1%	15.4%	21.2%	13.7%	9.2%	6.4%
• Large Farms	8.4%	13.2%	4.9%	11.7%	0.4%	0.6%
Maize Expenditure Shares[b] **(% of hh expenditure on maize)**						
• Small Farms	29.0%	15.7%	24.1%	11.7%	11.2%	12.8%
• Large Farms	47.2%	2.6%	19.7%	49.8%	16.5%	19.5%

a. *Source:* Kenya Ministry of Agriculture

b. *Source:* Kenya Maize Impact Study

Table 5. Net Yield Gains and Input Demands Associated with Zone-specific Technologies

Zone[a]	Source of yield gains (%)			Net Yield Gain	Labor Demand Increase	Fertilizer Demand Increase
	Breeding	Crop Management	Technology Transfer			
Lowlands	14%	37%	49%	7.4%	11.6%	5%
Dry Midaltitude	0%	51%	49%	13.0%	11.3%	2%
Moist Midaltitude	7%	56%	37%	14.4%	11.6%	5%
Dry Transition	30%	33%	37%	28.2%	10.8%	2%
Moist Transition	64%	6%	30%	29.7%	5.9%	6%
Highlands	45%	3%	52%	8.8%	5.5%	6%

a. Lowlands, Dry Midaltitude, Moist Midaltitude, and Dry Transition are marginal agroecological zones. Moist Transition and Highlands are favored agroecological zones.

Source: Mills (1995)

Table 6a. Open Economy (Fixed Price) Model Results: Technological Change in Marginal Agroecological Zones Only[a]

	Marginal Agroecological Zones				Favored Agroecological Zones			
Variable	**Lowlands**	**Dry Midaltitude**	**Moist Midaltitude**	**Dry Transition**	**Moist Transition**	**Highlands**	**Urban**	**National**
	---% changes---							
Maize production	7.05	12.65	13.99	27.83	-0.54	-0.54		4.46
Farm profits								
▪ Small farms	-1.29	-3.15	0.25	3.29	-1.33	-1.15		
▪ Large farms	-1.87	-1.57	-2.08	-0.45	-0.90	-0.91		
Real Income per capita								
▪ Small farms	0.48	-0.61	2.25	3.29	0.23	-0.21		
▪ Large farms	0.08	0.32	-1.21	0.96	-0.82	-0.79		
▪ Urban households							0.00	
Price Index								
▪ Small farms	0.00	0.00	0.00	0.00	0.00	0.00		
▪ Large farms	0.00	0.00	0.00	0.00	0.00	0.00		
▪ Urban households							0.00	
Real Agricultural Wage								6.75
General Price Index								0.00
Imports								-15.32

a. Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to a baseline in which no technological change takes place and population growth follows recent patterns.

Table 6b. Open Economy (Fixed Price) Model Results: Technological Change in Favored Agroecological Zones Only[a]

Variable	Marginal Agroecological Zones				Favored Agroecological Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
	---% changes---							
Maize production	-0.10	-0.10	-0.12	-0.12	29.54	8.64		14.40
Farm profits								
▪ Small farms	-0.22	-0.56	-0.74	-0.57	10.86	2.08		
▪ Large farms	-0.47	-0.43	-0.98	-0.40	11.70	1.53		
Real Income per capita								
▪ Small farms	0.22	0.08	0.34	0.09	6.04	1.75		
▪ Large farms	0.06	0.12	-0.66	0.15	11.16	1.45		
▪ Urban households							0.00	
Price Index								
▪ Small farms	0.00	0.00	0.00	0.00	0.00	0.00		
▪ Large farms	0.00	0.00	0.00	0.00	0.00	0.00		
▪ Urban households							0.00	
Real Agricultural Wage								2.02
General Price Index								0.00
Imports								-49.12

a. Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to a baseline in which no technological change takes place and population growth follows recent patterns.

Table 6c. Open Economy (Fixed Price) Model Results: Technological Change in All Agroecological Zones[a]

	Marginal Agroecological Zones				Favored Agroecological Zones			
Variable	**Lowlands**	**Dry Midaltitude**	**Moist Midaltitude**	**Dry Transition**	**Moist Transition**	**Highlands**	**Urban**	**National**
	---% changes---							
Maize production	6.95	12.55	13.87	27.71	29.00	8.10		18.86
Farm profits								
▪ Small farms	-1.50	-3.72	-0.49	2.72	9.53	0.93		
▪ Large farms	-2.34	-2.00	-3.05	-0.85	10.79	0.62		
Real Income per capita								
▪ Small farms	0.70	-0.53	2.59	3.38	6.27	1.54		
▪ Large farms	0.14	0.45	-1.87	1.10	10.34	0.66		
▪ Urban households							0.00	
Price Index								
▪ Small farms	0.00	0.00	0.00	0.00	0.00	0.00		
▪ Large farms	0.00	0.00	0.00	0.00	0.00	0.00		
▪ Urban households							0.00	
Real Agricultural Wage								8.77
General Price Index								0.00
Imports								-64.44

a. Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to a baseline in which no technological change takes place and population growth follows recent patterns.

Table 7a. Closed Economy (Flexible Price) Model Results: Technological Change in Marginal Agroecological Zones Only[a]

Variable	Marginal Agroecological Zones				Favored Agroecological Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
	% changes							
Maize production	6.23	10.98	12.72	26.42	-2.11	-1.89		3.03
Farm profits								
▪ Small farms	-1.25	-4.04	-2.61	2.44	-3.36	-2.99		
▪ Large farms	-3.76	-2.41	-5.09	-0.12	-3.00	-1.99		
Real Income per capita								
▪ Small farms	1.72	-0.60	2.08	3.24	-0.42	-1.07		
▪ Large farms	1.32	-0.18	-2.87	3.28	-2.12	-0.86		
▪ Urban households							0.44	
Price Index								
▪ Small farms	-1.23	-0.67	-1.02	-0.50	-0.47	-0.54		
▪ Large farms	-2.00	-0.11	-0.83	-2.11	-0.70	-0.40		
▪ Urban households							-0.44	
Real Agricultural Wage								6.96
General Price Index								-0.62
Real Maize Price								- 3.61

a. Assumes no change in maize imports. All values denote percentage changes relative to a baseline in which no technological change takes place and population growth follows recent patterns.

Table 7b. Closed Economy (Flexible Price) Model Results: Technological Change in Favored Agroecological Zones Only[a]

Variable	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	Urban	National
	Marginal Agroecological Zones				Favored Agroecological Zones			
	----% changes----							
Maize production	-2.74	-5.46	-4.19	-4.63	24.51	4.32		9.80
Farm profits								
▪ Small farms	-0.10	-3.38	-9.90	-3.28	4.33	-3.81		
▪ Large farms	-6.55	-3.13	-10.64	0.64	4.96	-1.94		
Real Income per capita								
▪ Small farms	4.20	0.13	-0.19	-0.05	3.99	-0.99		
▪ Large farms	4.06	-1.50	-5.96	7.61	6.98	-0.52		
▪ Urban households							1.43	
Price Index								
▪ Small farms	-3.94	-2.13	-3.27	-1.59	-1.52	-1.74		
▪ Large farms	-6.41	-0.35	-2.68	-6.76	-2.24	-1.29		
▪ Urban households							-1.43	
Real Agricultural Wage								2.70
General Price Index								-2.00
Real Maize Price								- 11.59

a. Assumes no change in maize imports. All values denote percentage changes relative to a baseline in which no technological change takes place and population growth follows recent patterns.

Table 7c. Closed Economy (Flexible Price) Model Results: Technological Change in All Agroecological Zones[a]

	Marginal Agroecological Zones				Favored Agroecological Zones			
Variable	**Lowlands**	**Dry Midaltitude**	**Moist Midaltitude**	**Dry Transition**	**Moist Transition**	**Highlands**	**Urban**	**National**
	---% changes---							
Maize production	3.49	5.53	8.54	21.79	22.40	2.43		12.83
Farm profits								
▪ Small farms	-1.35	-7.42	-12.51	-0.84	0.96	-6.80		
▪ Large farms	-10.32	-5.54	-15.73	0.51	1.96	-3.94		
Real Income per capita								
▪ Small farms	5.93	-0.47	1.89	3.19	3.57	-2.06		
▪ Large farms	5.38	-1.69	-8.83	10.89	4.86	-1.93		
▪ Urban households							1.87	
Price Index								
▪ Small farms	-5.17	-2.80	-4.29	-2.09	-2.00	-2.28		
▪ Large farms	-8.41	-0.46	-3.51	-8.87	-2.94	-1.69		
▪ Urban households							-1.87	
Real Agricultural Wage								9.66
General Price Index								-2.62
Real Maize Price								- 15.20

a. Assumes no change in maize imports. All values denote percentage changes relative to a baseline in which no technological change takes place and population growth follows recent patterns.

Table 8. Aggregate Income Effects of Various Technological Change Scenarios[a]

Closure Condition	Technological Change Occurs in:	Aggregate Increase in Real Income (%)
Fixed price	Marginal zones only	0.33
Fixed price	Favored zones only	1.84
Fixed price	All zones	2.17
Flexible price	Marginal zones only	0.18
Flexible price	Favored zones only	1.31
Flexible price	All zones	1.48

a. Computed as the sum of real income increases reported in Tables 6a – 7c, weighted by household-zone specific population shares.