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dissertation entitled

The Impact of Maize Technologies on Income Distribution in Marginal and High Potential Regions of Kenya

presented by

Daniel David Karanja

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in **Agricultural Economics**

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Date **June 24, 2003**

THE IMPACT OF MAIZE TECHNOLOGIES ON INCOME DISTRIBUTION IN MARGINAL AND HIGH POTENTIAL REGIONS OF KENYA

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics

2003

ABSTRACT

THE IMPACT OF MAIZE TECHNOLOGIES ON INCOME DISTRIBUTION IN MARGINAL AND HIGH POTENTIAL REGIONS OF KENYA

By

Daniel David Karanja

The need to feed a rapidly growing population on declining per capita arable land and dwindling research and development (R&D) resources is a common reality in many developing countries and has increased pressure for governments and donors to fund priority R&D activities that promise the greatest welfare benefits. In addition, many R&D institutions are struggling to identify and allocate scarce resources among competing research agenda and target regions. This debate is crucial in Kenya, especially because agriculture is the major source of food, income and livelihood for the majority of the population, and it has been performing poorly lately.

The objectives of this study are: (1) to provide a comprehensive review of production and technology of Kenya's most important staple crop, maize; (2) to evaluate the differential impacts of maize technologies diffusion on farm profits and income distribution for different households and regions; and (3) to help policy makers and research managers make informed decisions on investments in Kenyan maize R&D. To achieve these objectives, this study uses a GIS-referenced farm- and village-level survey data collected in 1999 from 426 farmers in 30 population clusters. This and other secondary data are used to construct multi-market models that simulate differential impacts of maize technologies on farm profits and income for various households and regions. Gini

coefficients are calculated to gauge income distribution effects of those technologies. Simulating impacts of technological change through input and product markets reveals great insight into the distributional implications of alternative technology diffusion patterns.

The results of the simulations indicate several things. First, without technological change, Kenya will suffer a large deficit in maize output, necessitating greater maize import to meet consumer demand or suffer unsustainable increases in maize prices in future. Second, maize technologies that have been developed for high potential regions will continue to have more profound aggregate impacts on maize production, leading to reduction in import demand (if maize prices are controlled) or reduction in maize prices (if maize prices are flexible).

Third, diffusion of maize technologies in the high potential regions has substantially greater positive impacts on aggregate real income and farm profits, with or without accompanying diffusion in marginal regions. However, technology diffusion in the marginal regions has better income distribution effects than when technology diffusion occurs only in the high potential regions, or in both regions. Lastly, the way in which the maize market clears has important ramifications for both the magnitude and distribution of gains and losses from various technology adoption scenarios. In general, aggregate incomes are greater when maize prices are controlled than when the prices are flexible. A notable exception is in urban households, whose welfare improves when maize prices are flexible but remains unchanged when maize prices are fixed and unchanged.

DEDICATION

First, this study is dedicated to the Almighty God and to my Lord and Savior, Jesus Christ, whom I give all the glory, honor and praise! His divine mercy and strength has brought me this far! I thank Him for the courage, perseverance and all the resources I needed, and for miraculously healing my wife in Lansing, Michigan. Glory to God in the highest! Amen.

Secondly, I dedicate this work to my dear wife, Dr. Lucy W. Karanja, and our three lovely children: Janet (9 years old), Michael (6 years old) and Elyon (2 years old). Their love and patience strengthened my resolve. And lastly, to my mother (Janet Wanjiru), mother-in-law (Serah Ngendo) and father-in-law (John Muchina), who tirelessly supported and prayed for my family and me. I love you all and may God richly bless you.

ACKNOWLEDGMENT

First, I acknowledge the Chairman of my dissertation committee, Dr. Eric W. Crawford for his support and kindness to my family. Indeed, Dr. Crawford has been more than just an advisor to me. I am grateful to my thesis supervisor, Dr. Mitch Renkow of North Carolina State University. His insight and experience with multi-market modeling made my work a whole lot easier. I appreciate comments and support from my committee members: Drs. Tom Reardon, Scott Swinton, John Hoehn and Carl Liedholm, all of Michigan State University. I also feel indebted to Dr. Carl K. Eicher, my major professor during my Masters degree program at Michigan State University in 1988-90, for encouraging me along this journey.

I am also grateful for the goodwill of Drs. Cyrus Ndiritu, Joseph Wanjama and Adiel Mbabu, former directors at the Kenya Agricultural Research Institute, respectively; the support towards my tuition and research from the Rockefeller Foundation (New York); and partial funding for my field research in Kenya from CIMMYT's Economic Program (Mexico). I wish also to thank all my Christian brothers and sisters who believed God with us through the years, including the African Christian Fellowship (Lansing Chapter) the Fellowship of Christian Internationals and Friends (Trinity Church, Lansing) and "At His Feet" Fellowship, which met at our home on Fridays. God keeps all His promises!

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KEY TO ABBREVIATIONS

CBS	Central Bureau of Statistics
DMA	Dry Midaltitude zone
DRSRS	Department of Remote Sensing and Resource Surveys
DT	Dry Transition zone
HT	Highlands zone
IMF	International Monetary Fund
KARI	Kenya Agricultural Research Institute
KMDP	Kenya Maize Database Project
KMIS	Kenya Maize Impact Study
LT	Lowlands zone
MMA	Moist Midaltitude zone
MT	Moist Transition zone
NASSEP III	National Sample Surveys and Evaluation Program
NCPB	National Cereals and Produce Board
R&D	Research and Development
T&V	Training and Visit
WMS	Welfare Monitoring Survey

CHAPTER 1

1.1 Introduction

The need to feed a rapidly growing population on declining per capita arable land and dwindling research and development (R&D) resources is a common reality in many developing countries and has increased pressure for governments and donors to fund priority R&D activities that promise the greatest welfare benefits (Renkow, 1993). In addition, many R&D institutions are struggling to identify and allocating scarce resources among competing research agenda and target regions. The quest to do this assumes greater significance in Sub-Saharan Africa (SSA), which is the only region in the world that is experiencing declining per capita food production, rapid population growth and serious economic stagnation (World Bank, 2001).

Conventional wisdom suggests that in order to sufficiently improve agricultural productivity, investments in R&D should be made in high potential regions rather than in marginal regions. The argument is that greater productivity in the high potential regions will generate faster economic growth, greater employment, higher wages and lower food prices that will benefit the country more, especially the poor. In additional, there will be less pressure to cultivate fragile marginal lands thereby reducing environmental degradation. Moreover, investments in marginal areas historically have been low because of poor returns, and diverting research resources away from the high potential regions may do more harm than good (Coxhead and Warr, 1991; Renkow, 2000).

An alternative hypothesis suggests that increased public investments in "less-favored", marginal regions can generate competitive or greater agricultural growth than comparable additional investments in high potential regions. The argument cites the fact that past investments in agricultural development tended to focus on irrigated agriculture and high potential regions and never resolved increasing poverty, hunger and food insecurity problems in the marginal regions. Coupled with increasing evidence of stagnation in agricultural productivity growth in high potential areas, this strategy proposes that more investments in marginal regions' agriculture may yield higher aggregate social returns, given that most of the poor are located in these regions, compared to investments in high potential regions (Fan and Hazell, 2001). Also, if the bulk of past agricultural research investments were made in high potential regions, the incremental rate of return to investment may decline to the point where it competes with, or is surpassed by, investments in marginal regions (Byerlee and Morris, 1993).

This debate is critical in Kenya and many other African countries that face a severe food, agricultural or economic crisis. Since agriculture is the dominant sector of the economy and provides food, employment and income to 70-80% of poor people who live in rural areas, the best way to achieve poverty reduction and welfare gains is to increase agricultural productivity, improve access to food and markets, and invest in supporting infrastructure, institutions and policies. Increases in agricultural productivity will, in turn, provide better access to non-tradable and semi-tradable foods, and improve rural and urban employment and wages.

This study contributes to the debate by using cross-sectional, farm- and village-level data, as well as other secondary data, to evaluate the impact of maize technologies on income distribution in different households and regions, while providing information on the status of maize production and technology in a way that aids decision-making concerning investments in maize R&D in Kenya. A multi-market model framework is used to provide insight on how the technology works through output and input markets to distribute benefits and losses to different farm households (those adopting and non-adopting; net producers and net consumers; small and large scale farms; and urban consumers). Such analysis provides valuable information for Kenyan policy makers and research managers to make objective decisions about specific maize technological investments.

1.2 Problem Statement and Study Objectives

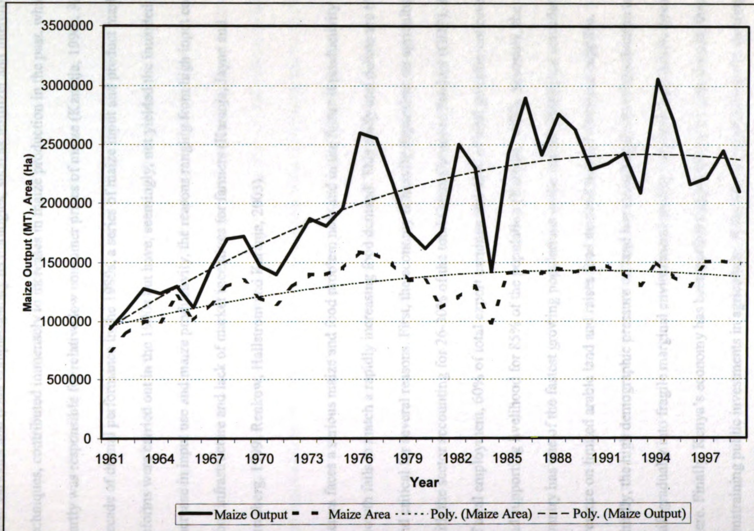
Globally, maize ranks second to wheat in terms of production output, but in Africa it ranks first. Maize is the most widely grown cereal crop, with seventy countries, each planting more than 100,000 hectares (Ha) of maize. It is grown in diverse regions, elevations and production cycles (Dowswell, Paliwal and Cantrell, 1996). Five hundred million metric tons (MT) of maize are produced on 130 million Ha annually in the world. Twenty of the largest maize-producing countries account for 91% of the global output and 80% of the global maize area. Kenya's share in the global maize production and area are 0.6 and 1.2%, respectively (FAOSTAT, 2001).

Despite a small global share, maize is Kenya's staple food. The crop, introduced into Kenya about a century ago, is grown in almost all agro-ecological zones on nearly two-thirds of the total food crop area (Hassan and Karanja, 1997). The crop's popularity has surpassed that of other traditional cereals, such sorghum and millets, due to ease of cultivation, storage and processing, resistance to pests and diseases, and utilization in many forms. Maize supplies large shares of proteins and calories for the majority of poor people, and dominates food policy decisions in Kenya, to the extent that insufficient domestic supplies of maize easily translate into major food shortages and, often, famine (Blackie, 1990; Karanja, 1990).

In general, Kenya produces sufficient quantities of maize in most years, except in adverse weather. Figure 1 shows the trends of area and production of maize in Kenya between 1961-99. The trend reveals increasing maize production and area between 1963-77, a "peak" on both area and production between 1991-94, and a decline followed afterwards. The increase between 1963-77 is attributed to increased availability and use of new maize varieties while the latter stagnation reflects a slower uptake of new technologies or few newer technologies available to farmers, a limited capacity for area expansion, and adverse weather and poor policy environment effects (Hassan and Karanja, 1997).

The remarkable past progress in maize production in Kenya was a product of consistent development and injection of new streams of maize technologies from the public-funded agricultural research institutes, now coordinated under the Kenya Agricultural Research Institute (KARI). This research system has over the years developed more than 25 maize

Figure 1: Kenyan Maize Output and Area, 1961-99



varieties targeted for different agro-climatic zones across the country. The adoption of these varieties and other complementary technologies, such as fertilizer and intercropping techniques, contributed immensely to increases in maize production in the past, which partly was responsible for relative low consumer prices of maize (Karanja, 1990). After a decade of dismal performance in the 1980s, a series of maize input and product market reforms were carried out in the 1990s but have, seemingly, not yielded the intended increase in input use and maize productivity, the reasons ranging from high input cost to poor infrastructure and lack of market incentives for farmers (Karanja, Jayne and Strasberg, 1999; Renkow, Hallstrom and Karanja, 2003).

Kenya faces a serious maize and food problem now and in the future if productivity growth fails to match a rapidly increasing food demand. This study and debate are timely and critical for several reasons. First, the economy is heavily dependent on agriculture, with the sector accounting for 26-30% of the total Gross Domestic Product (GDP), 80% of total employment, 60% of total export earnings and 45% of total government revenue, and supporting livelihood for 85% of the population (Karanja, 1990). Secondly, the country has one of the fastest growing populations in the world, which puts considerable pressure on limited arable land and raises food demand beyond domestic supplies. Thirdly, the high demographic pressure on land has caused agricultural production to shift gradually into fragile marginal environments posing a serious degradation threat there. Finally, Kenya's economy has been performing poorly in the past decade, thus constraining public investments in agriculture. A decade of suspended donor funding, three years (1999-2001) of the worst drought in 42 years and stress from transition politics combine to create a potential political and economic crisis.

Because of limited capacity for expansion of arable land, future increases in agricultural productivity will largely rely on yield improvement (Karanja, 1996; Byerlee and Eicher, 1997). Therefore, investments in agricultural innovations that increase yields through genetic improvement, agronomic husbandry or technology diffusion will be crucial. However, concerns arise about the differential impacts of resource allocation decisions and investment in such agricultural technologies on the welfare of different households and regions (Renkow, 1993). For Kenya, the concern is the differential effects on small versus large farmers and high versus marginal potential regions, hence this analysis uses these classifications of farmers and regions to shed light on this issue. The investment and policy choices that maize research managers in Kenya make has important implications on whether those strategies will reduce or aggravate current levels of hunger and poverty through their impacts on the farm income and its distribution.

Currently, farmers achieve, on average, between 20-60% of the yield levels attained in research centers (Hassan, et al. 1998). This gap is attributed to various constraints that include a low use of existing maize technologies and may point to a potential for productivity growth waiting to be exploited by better targeting of those technologies and facilitation of their adoption (Hassan and Karanja, 1997; Matlon and Spencer, 1985). This study evaluates the impact of such potential ('on-the-shelf') maize technologies on farm income and its distribution, where these are used as measures of farm welfare, on different households and regions. Since maize is the major staple and accounts for large production and consumption shares for the majority of Kenyans, any policy choices and potential changes in maize productivity and incomes will have far-reaching economic welfare and poverty reduction impacts. Therefore, this study has three main objectives:

1. To provide a review of the status of maize production and technology in Kenya.
2. To evaluate the differential impact of the diffusion of maize technologies on farm profit and income distribution for different households and regions; and
3. To help policy makers and research managers make informed decisions on investments in maize R&D in Kenya.

1.4 Methodology and Organization of the Study

1.4.1 Sampling Strategy and Data

This study used a GIS-referenced multi-stage stratified random sampling frame that was created by a KARI project, the Kenya Maize Database Project (KMDP) back in 1992 (Hassan, Lynam and Okoth, 1998). Agro-climatic characteristics, population density and intensity of maize production were used to define homogenous maize production zones. The sampling sites were randomly selected from the National Sampling Frame of the National Sample Surveys and Evaluation Program (NASSEP III), Central Bureau of Statistics, which contains 1048 rural and 324 urban population clusters (Kenya, 1994). Since these sites were well distributed across maize-growing regions, the current study randomly selected 30 survey clusters and 426 farmers out of the 65 clusters and 1407 farmers used by the KMDP project. The distribution of farmers between different zones was determined by the relative importance of maize in each zone, logistical considerations and available research funds. Table 1 shows the final distribution of selected farmers and survey sites by administrative district and agro-climatic zone. The farmers were interviewed using farm- and village-level questionnaires (in the Appendix).

Secondary data, complementing the primary data collected in 1999, included:

1. Maize production data for 1992-98 from the Department of Resource Surveys and Remote Sensing;
2. Commodity price data for 1995-99 and different spatial markets from the Market Information Branch, Ministry of Agriculture;
3. Climate data for updating the GIS information from the Department of Meteorology.
4. Data on infrastructure to supplement village-level survey from the Ministry of Transport Communications and Public Works;
5. Detailed data on welfare attributes of sampled clusters from the Welfare Monitoring Survey of the Central Bureau of Statistics, Office of the Vice-President and Ministry of Planning and National Development; and
6. Regional farm production data from the Department of Rural Planning, Office of the Vice-President and Ministry of Planning and National Development.

These primary and secondary data are used to generate parameters needed to simulate impacts of maize technologies on income and farm profits for different households and regions using fixed-price and flexible-price multi-market models. The multi-market models are preferred because they allow detailed household-level analysis, especially when farmers are a mixture of producers, consumers and labor suppliers, a situation that would present complications in typical economic surplus models.

Table 1: Distribution of Farmers by District and Zone

District	Marginal Potential Zones				High Potential Zones		All Zones
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	
Bondo			15				15
Bungoma					15		15
Busia			15				15
Embu		15			15		30
Gucha					15		15
Kakamega					15		15
Kilifi	15						15
Kwale	30						30
Machakos				15			15
Makueni		15					15
Malindi	15						15
Maragua				15			15
Meru				15			15
Mwingi		15					15
Nakuru						48	48
Nyamira						15	15
Nyandarua						15	15
Rachuonyo			15				15
Trans Nzoia					42		42
Tharaka		15					15
Uasin Gichu						36	36
Total	60	60	45	45	102	114	426

Disaggregating simulated impacts of technological change across different household types and regions, as well as across input and product markets, reveals greater insight into the distributional implications of alternative technology diffusion patterns. The model analysis used is similar to Renkow (1993) but it considers six agroclimatic zones instead of two and does not differentiate between low- and high-income urban populations.

1.4.2 Organization of the Study

This study is organized as follows. Chapter 2 provides a detailed descriptive analysis of maize farming and technology in Kenya. This updates information on maize farming and technology in Kenya, as differentiated by small and large farmers in marginal and high potential regions. Maize policy decisions are considered on the basis of these categories. The chapter also outlines information on maize input and product markets, and changes that may have taken place after market liberalization in the early to mid-1990s.

Chapter 3 presents a literature review on the impact of technological change on farm productivity, income and welfare. It also lays out the structural details of the basic analytical framework or multi-market models used in this study and outlines how different parameters for the models are computed. Chapter 4 presents the results and discussions from a simulation of a fixed-price and a flexible-price model of technological change, including calculating Gini coefficients from the scenarios considered to determine the income distribution effects of maize technology diffusion. Chapter 5 summarizes the results and draws the implications for research and policy.

CHAPTER 2

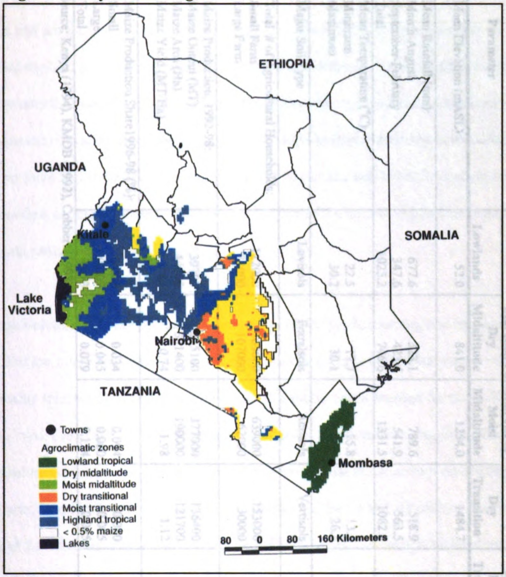
2.1 Characterizing the Maize Production Environment

Assessment of the impact of technological change on income and welfare in different households and regions requires careful characterization of the production environment, farm technology and its users, measures of specific technology effects on income, and understanding of how the market distributes output gains and losses. To characterize the production environment, this study used the maize zone classification developed in 1992 by the Kenya Agricultural Research Institute.[1] The advantage of the new classification over the previous Jaetzold and Schmidt (1983) is that it is digitally referenced using Geographical Information Systems, making it easier to use, update and adjust.

Figure 2 is presented in color and shows the six classified maize production zones used in this study: (1) the Lowlands zone; (2) the Dry Midaltitude zone; (3) the Moist Midaltitude zone; (4) the Dry Transitional zone; (5) the Moist Transitional zone; and (6) the Highland zone. Table 2 summarizes the agro-climatic, demographic and maize production characteristics of these zones, which indicate significant zonal variations. The March-August season is the major season for most of Kenya's maize producing regions and has greater rainfall amounts. The September-February season has less rainfall but is more important for parts of the Moist Midaltitude, the Dry Midaltitude and Dry Transition zones.

[1] Corbett (1998) has details of how these zones were created and classified.

Figure 2: Kenyan Maize Agro-Climatic Zones



Source: Hassan (1998)

Table 2: Basic Agro-Climatic, Demographic and Maize Production Characteristics by Zone

Parameter	Marginal Potential Zones				High Potential Zones		All Zones
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	
Mean Elevation (mASL)	52.0	841.0	1254.0	1484.7	1555.1	2267.3	-
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 (°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 # of Agricultural Households:							
Small Farm	112000	469000	639000	153000	992000	628000	2992000
Large Farm	24000	107000	62000	30000	107000	88000	418000
Maize Production, 1992-98:							
Maize Output (MT)	39700	245100	377000	136400	1076400	686100	2560700
Maize Area (Ha)	44800	331400	190000	121700	441000	311300	1440200
Maize Yield (MT/Ha)	0.89	0.74	1.98	1.12	2.44	2.20	1.78
Maize Production Share1996-98 (%):							
Small	0.006	0.034	0.094	0.040	0.140	0.173	-
Large	0.007	0.045	0.060	0.005	0.280	0.116	-
Total	0.013	0.079	0.154	0.045	0.420	0.289	

Source: Kenya (1994), KMDB (1992), Cobbert (1998).

Nitosols are the best soils for maize production and major soils in the high potential regions and are the best for maize production. In contrast, the soil types found in the marginal regions, such as the Vertisols, Ferralsols and Acrisols, have less potential for maize productivity compared to Nitosols.[2] These and other agro-climatic characteristics influence the choice of maize varieties, the production potential and crop seasonality, and based on them and for purposes of this study, the Highlands and Moist Transition zones are classified as "high potential" regions and the rest of the zones are considered as "marginal potential" maize regions.

The high potential regions are the most important maize production regions and account for half of the total area under maize and more than two-thirds of the total maize output. Contrasting this, the Dry Midaltitude and Dry Transition zones account for about 30% of the total maize area and 15% of the total maize output. The Lowland zone is the least important maize producing area and yields 1.6% of the total maize output on 3% of total maize area. The 1992-98 average maize area and production was 1.44 million hectares (Ha) and 2.56 million metric tons (MT), respectively, giving an average national maize yield of 1.78 metric tons per hectare (MT/Ha). Small farms produced about half of the maize in 1996-98 and accounted for 88% of all rural agricultural households in Kenya.[3]

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[2] Soil names used here refer to FAO-UNESCO (1974) classification units.

[3] This study uses 10 acres as cut-off size for differentiating small and large farms.

2.2 Characterizing Maize Farming

Hassan (1998) presents a detailed description of maize farming in Kenya based on data collected in 1992. Since then, significant changes in maize policy and institutions have taken place. This study updates that information and provides a comprehensive characterization of maize farming and technology in Kenya. Table 3 presents a summary of maize farm and farmer characteristics among small and large farms in the six maize zones. The mean farm size among small and large farms was 1.32 Ha and 109.74 Ha, respectively, and for marginal and high potential regions 2.3 Ha and 37 Ha, respectively. The overall mean farm size was 19.90 Ha while the median farm size was 1.27 Ha.

The average proportion of female farmers was 45% for the entire sample, with significant variance observed by household group and zone. Fifty percent of the small farmers were women, compared to only 18% among large farmers. The proportion of women farmers was noticeably higher among small farmers in the marginal zones, the Dry Midaltitude and Dry Transitional zones, than in the other zones. This may reflect a bias against women on land distribution and/or access, or a reflection a higher likelihood of men in these zones to seek off-farm employment to supplement farm income.

Seventy-two percent of all the farmers had some formal education.[4] This compares to Kenya's average of 83% (Kenya, 1998). Farmers in the Lowland zone were the least educated whereas those in the Moist Transition and Highlands were the most educated.

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[4] Education refers to "years of formal schooling".

Table 3: Maize Farm and Farmer Characteristics by Farm Size and Zone

Parameter	Marginal Potential Zones				High Potential Zones		All Zones
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	
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	42	59	43	58	47	53	50
Large	30	17	0	-	13	21	18
% Illiterate Farmers:							
Small Farm	45	32	17	25	23	33	29
Large Farm	70	33	38	-	19	6	23
Age of Farmer (Years):							
Small	43	45	43	44	41	44	43
Large	44	58	56	-	50	46	49
% Farm (Crop) Area Under Maize:							
Small	50 (68)	62 (76)	48 (67)	69 (79)	56 (64)	61 (75)	58 (71)
Large	25 (62)	15 (76)	20 (49)	-	54 (76)	25 (38)	30 (68)
Maize Planting Month:							
Small	Mar/Apr	Oct/Nov	Feb/Mar	Sep/Oct	Mar/Apr	Mar/Apr	Mar/Apr
Large	Mar/Apr	Oct	Feb/Mar	-	Mar/Apr	Mar/Apr	Mar/Apr
Maize Harvesting Month:							
Small	Jul/Aug	Feb/Mar	Jul/Aug	Feb/Mar	Aug/Sep	Nov/Dec	Jul/Aug
Large	Jul/Aug	Feb/Mar	Jul/Aug	-	Nov/Dec	Nov/Dec	Nov/Dec

Overall, 71% of all the small farmers and 77% of all the large farmers had formal education, and further comparison revealed that twice as many large farmers as small farmers had higher levels of education. The overall mean age of the farmers was 44 years, indicating a relatively aged farming community. Large farmers were relatively older (49 years) than small farmers (43 years).[5]

There was a notable differential allocation of land to maize by farm size and zone. On average, small farmers allocated twice (68%) as much of their total farm area to maize compared their large-scale counterparts (30%). Although most small and large farmers allocated nearly 70% of their total crop area to maize, this was untrue for large farmers in the Moist Midaltitude (49%) and the Highland (38%) zones. Notably, farmers in drier environments allocated more cropland (75%) to maize than the average.

Maize was planted at different times depending largely on the onset of rains. Thus, there was little variation between small and large farmers. Two distinct planting seasons are observed: February-April and October-November, with the majority of farmers planting in the former. Farmers in the Lowland, Moist Midaltitude, Moist Transition and Highland zones mostly planted their maize between February-April. On the contrary, most farmers in the Dry Midaltitude and Dry Transiton zones planted their maize in the October-November season.

[5] Average life expectancy in Kenya is 58 years for men and 61 years for women (World Bank, 2002).

Harvesting time depended on the length of the rainfall season and the maturity duration of the maize varieties planted by the farmers. The majority of farmers in the Dry Midaltitude and Dry Transition zones harvested their maize between February-March while in the Lowland and Moist Midaltitude zones, the majority harvested between July-August. Most farmers in the Moist Transition and the Highland zones harvested between November-December, apart from small farmers in the former zone who harvested between August-September because they planted shorter maturing varieties. Overall, the majority of small farmers harvested their maize in July-August period and large farmers in Nov-December period.

2.3 Current Maize Technologies

Karanja (1990) and Karanja (1996) provide a detailed historical perspective and evolution of maize research in Kenya, noting that past success of the maize research program was due to: (1) expansion of the research program to develop maize varieties suited to different agro-climatic regions; (2) the ability of the government to forge a public-private sector partnership to ensure the dissemination of the hybrid maize; (3) an aggressive agricultural extension program that planted field trials and taught farmers how to plant the new hybrids; and (4) guaranteed maize prices and markets for nearly 50 years. As a result, Kenya's maize research program is one of the most successful in Africa, and has developed over 25 maize varieties for the six agro-climatic zones, giving a range of varietal choices to farmers (Table 4). Current research is attempting to provide

Table 4: Maize Varieties in Kenya, 1961-99

Variety	Year Released	Maturity	Elevation	Yield[1] (MT/Ha)
Kitale Synthetic II	1961	Late	High	3.4
Katumani Synthetic II	1963	Early	Medium	2.0
H611	1964	Late	High	4.5
H621	1964	Late	High	4.1
H631	1964	Late	High	4.5
H622	1965	Medium	High	5.2
H632	1965	Medium	High	4.5
H612C	1966	Late	High	5.9
Katumani Composite A	1966	Early	Medium	2.3
Katumani Composite B	1968	Early	Medium	2.8
14511	1968	Medium	Medium	3.6
H512	1970	Medium	Medium	4.1
H6HC	1971	Late	High	5.9
H613C	1972	Late	High	6.0
Coast Composite	1974	Medium	Low	3.3
H614C	1976	Late	High	6.3
H625	1981	Late	High	6.8
H612D	1986	Late	High	6.4
H613D	1986	Late	High	6.0
H614D	1986	Late	High	6.6
H626	1989	Late	High	6.8
Dryland Composite I	1989	Early	Medium	2.9
Pwani Hybrid I	1989	Early	Low	3.8
H627	1989	Late	High	6.9
H628	1999	Late	High	7.1
H629	1999	Late	High	7.1

[1] Research yield potential
Source: Karanja (1990); Ochieng (1999)

regional specific agronomic recommendations using an eco-regional approach (Ochieng, 1999). Hassan and Karanja (1997) summarize the status of maize technology, adoption and productivity in 1992, before the government implemented drastic agricultural input and product market reforms. Mills (1998) went further and developed a framework for estimating ex ante impacts and priorities for maize technology in different zones using an economic surplus methodology.

Table 5 shows various parameters on maize technology and adoption. Sixty-two percent of all the farmers (61% of small farmers and 70% of large farmers) planted hybrid maize seed in 1998. This proportion varied by zone and household group. About 90% of small farmers and 97% of large farmers in the high potential regions planted hybrid maize. In marginal regions, less than one-fifth of large farmers and one-third of small farmers planted hybrid maize. Overall, H614 was the most popular variety and was planted by 46% of all farmers; the second popular varieties were "local" maize varieties, which were planted by 26% of all farmers.

Fifty-eighty percent of all farmers used basal fertilizer, with relatively more of the large farmers (73%) adopting basal fertilizer compared to the small farmers (55%). However, just like with hybrid seed, fertilizer adoption levels varied between different zones and household types, with higher adoption taking place in the high potential regions and

Table 5: Maize Technology Adoption and Yield Potential by Farm Size and Zone

Parameter	Marginal Potential Zones				High Potential Zones		All Zones
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	
Popular variety (% Using Hybrid):							
Small Farm	Local (6)	Katumani (35)	Local (46)	H511 (56)	H614 (91)	H614 (89)	H614 (61)
Large Farm	Local (10)	Katumani (17)	Local (13)	-	H614 (94)	H614 (100)	H614 (70)
% Using Basal Fertilizer							
Small Farm	6	24	45	27	86	93	55
Large Farm	0	17	38	-	100	100	73
Basal Fertilizer Level (Kg/Ha):							
Small Farm	1.3	20.4	22.9	32.6	83.9	80.3	48.7
Large Farm	0.0	41.2	37.1	-	177.5	131.0	105.2
% Using Tractor Tillage							
Small Farm	6	0	0	11	20	27	13
Large Farm	0	0	0	-	100	100	67
Major Intercrop (% Intercropped):							
Small Farm	Sorghum (69)	Beans (69)	Beans (81)	Beans (84)	Beans (65)	Beans (86)	Beans (75)
Large Farm	Cassava (70)	Beans (100)	Beans (50)	-	Beans (13)	Beans (45)	Beans (47)
Farmers' Yield, 1998 (MT/Ha):							
Small Farm	0.64	0.75	1.02	0.64	1.88	2.28	1.38
Large Farm	0.65	0.72	1.38	-	3.61	3.28	2.62
Farmers' Yield, 1992 (MT/Ha):[1]							
Small	0.61	0.71	1.48	0.81	1.99	1.82	1.59
Large	0.54	0.18	0.69	0.26	3.49	3.54	2.73
On-Farm Research Yield (MT/Ha):[2]	2.02	1.56	2.57	1.81	3.59	4.17	-
On-Station Research Yield (MT/Ha):[3]	3.55	2.50	4.30	2.50	5.63	6.52	-

[1] KMDP, 1992; [2] FURP/KARI, 1990; [3] Author's Computation

among large farmers; all large farmers and 80-84% of small farmers used fertilizer. Except in Moist Midaltitude zone, less than one-third of farmers in marginal regions used fertilizer.

The level of fertilizer application by farmers was lower than the recommended rate, except among large farmers in the highland regions. The average rate of fertilizer application for all small farmers was 48.7 Kg/Ha, compared to 105 Kg/Ha for large farmers, and 40% of the recommended rate. The overall average fertilizer rate was 58.3 Kg/Ha, half of the recommended level.

Besides seed and fertilizer, another important technological factor affecting maize production is the land preparation method. This affects farm productivity through the quality of the seedbed and timeliness of planting. According to Table 5, about 55% of all farmers used the hand-hoe to till their land, often delaying subsequent farm operations and experiencing lower farm yields. 23% of the farmers used a tractor and 22% used oxen plow. Only 13% of small farmers used a tractor for tillage compared to 67% for large farmers.

The most important crop inter-planted with maize was dry beans. This was true in all zones except the Lowland zone where sorghum was the most popular intercrop among small farmers and cassava among large farmers. About 75% of all small farmers intercropped their maize compared to 47% of all the large farmers. In almost all zones, more than half of the farmers intercropped maize, except among large farmers in the Moist Transition (45%) and the Highland zone (13%).

Table 5 also presents the maize research yields and farmers' yields in 1998 and 1992. The average yield in 1998 among small farmers was 1.38 MT/Ha while that of large farmers was nearly double that at 2.62 MT/Ha, with an overall average of 1.59 Mt/Ha. Farm yields varied from 0.64 MT/Ha among small farmers in the Lowland and Dry Transition zones to 3.61 MT/Ha among large farmers in the Moist Transition zone. Comparisons between yield levels in 1992 and 1998 show similar patterns and variations. The farm yields are also relatively lower than research yields, revealing yield gaps that can be exploited for productivity gains, even without developing new varieties.

2.4 Changes in Maize Technology Adoption, 1992-1998

Table 6 compares maize technology adoption between 1992 and 1998; over 90% of all the households sampled in 1998 had been sampled in 1992.[6] Overall, the number of farmers using hybrid maize seed declined by 5-6% while basal fertilizer usage improved by 9% among small farmers and 16% among large farmers. Significant increases also occurred for large farmers (17%) in the Dry Midaltitude, small farmers (25%) in the Moist Midaltitude zone and both small (35%) and large (37%) farmers in the Highland

[6] Major maize policy reforms occurred between these two time periods and are discussed in sections 2.5 and 2.6.

Table 6: Percentage Change in Maize Technology Adoption and Institutional Support, 1992-98[1]

Parameter	Marginal Potential Zones				High Potential Zones		All Zones
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	
% Using Hybrid Seed							
Small Farm	1	14	(1)	19	4	(6)	(5)
Large Farm	6	14	(60)	-	(6)	6	(6)
% Using Fertilizer							
Small Farm	6	9	25	(17)	13	35	9
Large Farm	0	17	0	-	7	37	16
Basal Fertilizer Level (Kg/Ha):							
Small Farm	1.3	(9.8)	(41.9)	(24.9)	(63.5)	26.4	(29)
Large Farm	0.0	41.2	10.5	-	32.5	70.6	35.2
Farmers' Yield, 1998 (MT/Ha):							
Small Farm	0.03	0.04	(0.47)	(0.17)	(0.11)	0.46	(0.21)
Large Farm	0.11	0.54	0.69	-	0.12	(0.26)	(0.11)
% Received Extension Advice:							
Small Farm	(21)	(37)	(41)	(45)	(59)	(36)	(43)
Large Farm	(30)	(47)	(51)	-	(73)	(33)	(46)
% Received Credit:							
Small Farm	1	2	0	7	(2)	(3)	0
Large Farm	0	0	(3)	-	(22)	(10)	(10)
% Net Sellers of Maize:							
Small Farm	13	13	17	(3)	24	27	15
Large Farm	(4)	0	24	-	32	49	24

Source: KMDB (1992); Karanja, 1999

[1] Figures represent 1998 level minus 1992 level; ( ) refers to negative value.

zone but a significant reduction of 17% was noted among small farmers in the Dry Transition zone.

The level of basal fertilizer shows a mixed picture with an overall reduction on the average level of fertilizer use by about 29 kg/Ha among small farmers compared to an average increase of about 35 kg/Ha among large farmers. Significant reductions in the rate of basal fertilizer applications were observed among small farmers in the Moist Midaltitude, Dry Transition and Moist Transition zones but there was a significant increase in the rate in the Highland zone. Large farmers in the Dry Midaltitude, Moist Transition and Highland zones recorded significant increases in the level of basal fertilizer use.

Given major policy and institutional changes that took place between 1992 and 1998, the observed changes in institutional access by farmers were profound. For instance, 43% of small farmers and 46% of large farmers had lost access to extension service in 1998 compared to 1992. This reduction was observed in all the zones and household types, with the worst reduction being in the most important maize-producing region, the Moist Transition zone. Access to farm credit for maize production was less dramatic, with access to small farmers remaining at 2% and for large farmers declining by 10 % between 1992 and 1998. However, there were significant increases in the number of farmers that had access to maize markets, an increase of 15% for small farmers and 24% among large farmers, confirming an increase in maize marketing after liberalization (Karanja, Jayne and Strasberg, 1999).

2.5 Agricultural Inputs, Markets and Prices

2.5.1 Land

Of Kenya's 57 million hectares of land, only 19% is considered having high and medium potential for agricultural use, and another 12% is good for livestock production (Kenya, 1998). The rest is arid and semi-arid land. Previously, agricultural production activities occurred only in the high potential regions using highly mechanized technologies on large farms averaging more than 50 hectares. But after Kenya's political independence in 1963, many large farms were bought and subdivided into smaller land units as part of a massive land re-distribution and settlement program.

As population increased, demographic pressure and customary bequeathing of land led to further subdivision of land. Consequently, per capita arable land has declined, especially in high potential regions, causing an increase in migration and settlement in fragile and marginal land. This trend exacerbates land degradation and loss of agricultural productivity. Table 7 shows this trend in per capita arable land, which has declined by more than 60% between 1970-2000 as a result of a rapid increase in rural populations and lack of sufficient arable land. Therefore, Kenya's future increase in maize production will have to rely more on higher yields through land-saving technologies rather than land area expansion. This entails reliance on availability and use of new and better technologies that raise productivity or reduce crop losses, while maintaining the natural resource base.

Table 7: Trends in Per Capita Agricultural Land Use, 1960-2000

Year	Cultivate Land ('000 Ha)	Agricultural Population ('000 People)	Per Capita Agricultural Land (Ha/Person)
1960	3900	7321	0.53
1970	3945	9858	0.40
1980	4280	13674	0.31
1990	4500	18728	0.24
2000	4520	22683	0.20

Source: FAOSTAT (2001)

Because of limited irrigation capacity, complementary, low-cost technologies that improve soil fertility and water retention or improve drought tolerance can greatly boost agricultural productivity. Alternatively, the limited irrigation potential can be used for high-valued crops to free up land in rain-fed regions for food crops such as maize while generating money to import additional foods. However, transformation of land through additional investments in irrigation may raise the value of land rental and purchase prices (Renkow, 1991).

Kenya's land market was very active after independence with large but differential transfers of land by farming enterprises and region. But low savings and lack of long-term credit opportunities has constrained land purchases. Often, land prices were distorted upwards by government subsidized loan programs that were more accessible to large farmers and people with higher social status. This hiked up land prices above the market value and made it difficult for poor people to access land. Moreover, the demand for land is depressed by reduced savings, which have to be accumulated over a long period. Also, the supply of land tends to be constrained by customary land tenure (Migot-Adholla, et al., 1991; Lyne, Roth and Troutt, 1997).

However, when compared in terms of costs to other land settlement programs in the world, Kenya's land transfer system was found to be cheaper and a better means of achieving equitable distribution of land resources, job creation and increasing overall demand for labor. Land exchange occurs in a variety of contractual modes ranging from seasonal rental to permanent transfer of ownership. Payments can precede or lag the flow of use of land, thus forming an inter-linked land and credit contract. Payments can be fixed in advance to be dependent upon the output from the land, forming an inter-linked land, labor and insurance contract. But none of these is a dominant practice in Kenya. Most holdings are acquired through inheritance of family land. However, because of limited cultivated land expansion, there has been an increase in incidences of renting land, especially from non-resident farmers. The scarce data available on this suggest little evidence on the relationship between land rental and land area but small farmers tend to rent more land than large farmers.

Often, those who rent land are poorer than those who lease land. Since rental fees are typically paid at the start of the contract, and a cash-flow problem is created by cultivation of the rented land, it is normal for tenants to be in net receipts of credit. Recent ethnic conflicts and land invasions in Kenya and Zimbabwe, and civil conflicts in Rwanda, Somalia and Burundi have tended to distort land markets and raise the risks and transaction costs of land ownership and farming. On the other hand, land adjudication and the issuance of title deeds have positively affected land investments and, in many cases, increased adoption of "lumpy" agricultural technologies and leading to improved land productivity.

2.5.2 Labor

Agricultural labor markets in many developing countries are less structured and, unlike industrial labor markets, selection of quality labor, supervision and investment in skill accumulation are less applicable. In general, basic skills are developed within the household or village. Quality variation between hired workers might be less significant and better known by employers, the latter frequently being close neighbors. Also, poor performance that may be instantly noticeable in an industry may be drowned by the combination of long lags in agricultural production function and the large random variations in productivity due to climate, diseases and pests. Moreover, specialization and division of labor is generally less exploited, especially in smallholder agriculture, as compared to industry. But most of all, poor enforcement of labor contracts, where such exist, has kept agricultural labor inefficient and unorganized.

Since many large farms operations in Kenya tend to be capital intensive, save for non-mechanized tasks such as harvesting maize, this section will focus on labor transactions in smallholder farming. The most striking fact about labor utilization in smallholder farming, even in the most commercialized commodities, is that hired labor forms only a small fraction of the total labor use and much of it is used to meet seasonal labor requirements rather than offset permanent differences in land/labor ratios between households. Of the hired labor used during the year, it is estimated that two-thirds of it is casual labor while a third is regular labor. Also, contrary to conventional wisdom, there is virtually no difference in the mean daily earnings between the two groups of labor.

Cross-sectional data used in this study reveals little variation between wages in different regions.

Hired labor in small farms is regionally differentiated is not surprising considering that most of it comes from casual labor hired by the day from the immediate neighborhood. Language barriers, lack of information and distance preclude long-distance labor migrations. Thus, intra-rural regional labor migrations are confined to employment on large plantations or estates, which are fewer now than years ago as a result of land sub-division. This was observed and confirmed with the data collected in this study: there were hardly any significant labor migration patterns between different villages, except for regions close to plantation farming such as parts of Moist Transition and Moist Midaltitude zones.

Labor sales data show evidence that, with dwindling farm sizes and increasing agricultural populations, a larger proportion of hired labor is from neighboring small farms rather than from rural landless laborers. Such labor, however, is merely a seasonal exchange and not large enough to even out the disparity in factor proportions between different farm categories. Moreover, the extent of small farm labor sales on non-small rural labor market is still limited by fewer large farm operations so that the only viable alternative for small farm labor is the informal "*Jua Kali*" rural enterprises, which in turn are constrained by lack of credit, technology and market information. Access to jobs in the formal sector in rural areas are limited and rationed by educational credentials while access to self-employment opportunities commonly require skills and finances, both of which are extremely scarce in rural areas. The only other alternative is employment in the informal sector in urban areas, which has been the main source of employment for rural youths escaping the consequences of rural unemployment. But urban wage rates have declined due to a high rural-to-urban migration and the current economic slump (Kenya, 2001).

Table 8 presents family and hired maize labor use and cost by zone and household type. On average, small farms are twice as labor intensive and use three times as much family labor on a hectare of maize as large farms. On the other hand large farms use 1.5 times more hired labor than small farms. There are, however, significant inter-zonal variations. For instance, in the Lowlands and Moist Midaltitude zones, small farms only used 28% more family labor than large farmers, whereas in the Moist Transition and Highland zones, the proportion was 93% and 83%, respectively. In general, large farms in these two zones tend to be highly mechanized and so use less manual, especially family, labor. Of specific interest to this study, farmers in marginal areas use more than 20% on average more total (both family and hired) labor on maize farming than those in high potential regions, mainly because maize technologies in the former regions tend to be more labor intensive.

On the allocation of labor to maize relative to other agricultural activities, small and large farms used about 58% of their family labor on maize. However, there were differences on hired labor: small farms allocated 26% of hired labor to maize compared to 47% by large farms. There was little inter-zonal and intra-zonal variation on these, except in the Moist

Table 8: Maize Labor and Wage Rate by Farm Size and Zone

Parameter	Marginal Potential Zones			High Potential Zones			All Zones
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	
Maize Family Labor, MD/Ha/Yr							
Small Farm	224	170	172	149	143	121	157
Large Farm	162	72	123	-	10	20	53
Maize Hired Labor, MD/Ha/Yr							
Small Farm	21	23	22	28	33	19	25
Large Farm	15	28	94	-	40	29	37
Maize Total Labor, MD/Ha/Yr							
Small Farm	245	193	194	175	176	140	182
Large Farm	175	100	216	-	50	49	90
1998 Wage Rate, Ksh/MD							
Small Farm	45.3	52.5	66.7	58.3	50.1	61.3	55.3
Large Farm	38.9	48.6	82.3	-	63.5	66.7	61.7
1999 Wage Rate, Ksh/MD							
Small Farm	60.3	69.1	75	62.5	62.5	77.2	68.4
Large Farm	66.7	65.3	91	-	77.1	83.3	78.0
% Family Labor Used on Maize							
Small Farm	64	52	64	59	54	60	58
Large Farm	56	53	58	-	74	52	58
% Hired Labor Used on Maize							
Small Farm	19	26	24	30	31	25	26
Large Farm	22	25	36	-	83	44	47

Transitional zone. Likewise, there was little differential between the wage rate paid out by small and large farmers in 1998 and 1999. In 1998, large farmers paid more than small farmers, on average, by about Kenya Shillings (Kshs.) 6.40 per manday (MD). In 1999, the difference was Kshs.9.60 per MD.[7] The observed inter-zonal wage differential was inadequate to compensate for any perceived or real transaction costs of migrating; and (2) there exists a high information cost to determining the wage differential.

2.5.3 Fertilizer

Soil nutrient depletion is widespread in Kenya (KARI, 1998). In the wake of declining per capita agricultural productivity, one of the nagging issue is how to manage soil fertility and improve crop production (Heisey and Mwangi, 1997). Because of land scarcity, dealing with declining land productivity may involve intensification of production through use of fertilizers and other land-augmenting technologies. Past experience indicate inorganic fertilizers hold great potential for nutrient replenishment and productivity-enhancement (Naseem and Kelly, 1999; Omamo and Mose, 2001).

The adoption and use of fertilizer and hybrid maize was instrumental for past increases of maize productivity in Kenya (Hassan et al., 1998; Karanja, Jayne and Strasberg, 1999). The decline in real price of, and concomitant government subsidy on, fertilizer between 1965-80, and expansion of fertilizer marketing channels through recruitment of fertilizer

[7] One man-day equals the amount of labor from one adult working 8 hours a day.

traders in almost every local trading center, contributed greatly to increased access and adoption of fertilizer.

However, foreign exchange constraints and input market liberalization accompanying the structural adjustment program of the late 1980s and early 1990s led to substantial increase in fertilizer prices and subsequent decline in fertilizer use (Hassan and Karanja, 1997; Argwings-Kodhek, 1997). In fact, whereas increase in land productivity between 1970-90 was due to increased use of hybrid maize and fertilizers, and supportive government policies, the decline in productivity between 1990-95 is attributed partially to a reduction in the use of fertilizer and hybrid seed (Nyoro and Jayne, 1999). Indeed, Table 6 suggests that there was a marginal decline in hybrid seed use and the level of fertilizer application. This, in part, was because input prices more than doubled after maize market reforms. Other constraints cited include poor infrastructure, lack of credit and markets, and high information and learning costs associated with specific agronomic recommendations (Heisey and Mwangi, 1997; Omamo and Mose, 2001).

Although the rate of adoption of fertilizer remains at about 58%, almost equal to the rate assessed in 1992, the level of application declined. Increases in the relative input-output price ratio, increased marketing costs and weather variability have left farmers more risk averse on fertilizer use, even in the high potential regions where maize response to fertilizer is highest. Further, use of fertilizer has become increasingly risky as incidences of poor quality seed and variations in onset of rains increase, resulting in a low fertilizer demand in both marginal and high potential regions.

Since most of the fertilizer is applied before or immediately after the rains, a failure or false onset of rains can actually lead to greater yield losses with than without fertilizer use. Also, since the outlay for fertilizer is in cash, use of adequate amounts of fertilizer becomes a hard decision for small, resource-constrained farmers, who have no access to credit. Unless fertilizer prices are brought down through improvement of the marketing chain and rural roads infrastructure as well as the establishment of a competitive private sector transport and trading regime, the fertilizer revenue-cost ratio will not be attractive enough to stimulate adoption and use to the desired rates for increased maize productivity. The increase of private traders, ranging from specialized large-scale importer-distributors to diversified small-scale retailers, is a promising sign of an emerging competitive market.

2.6 Maize Marketing and Consumption

Because of the strategic importance of maize in Kenya, the government has literally controlled both domestic and international marketing of the commodity since 1942. The government set both producer and consumer prices each year at the beginning of the planting season, maintained domestic maize movement controls, controlled all external trade and took care of a national strategic reserve. However, this changed dramatically in the late 1993 when, under pressure from donors and the structural adjustment program, the government eliminated movement controls on maize trading, deregulated maize and maize meal prices, and eliminated direct subsidies on maize sold to registered millers

(Jayne and Kodhek, 1997). Hence, the sole government maize marketing agent, the National Cereals and Produce Board, was reduced to "a buyer of last resort and custodian of a national strategic food reserve".

Prior to that, the board facilitated maize marketing by opening maize depots in almost all trading centers and building large silos in surplus maize producing locations. But due to high maintenance costs of the network and bureaucracy, the board posted net losses for 14 consecutive years (World Bank, 1995). Its operations reflected a long-lasting government policy dilemma of maintaining profitable producer prices and affordable consumer prices that became fiscally unsustainable and led to its succumbing to maize market reforms.

The reform process was expected to reduce maize marketing costs by encouraging more private sector participation and enhancing market competition. Instead, the process has been slow, frustrating and marked by a series of advances and reversals, especially with regard to private sector participation (Nyoro, Kiiru and Jayne, 1999). The resistance by the government to let go of maize market control was partly based on the premise that after liberalization maize producers and consumers will be exposed to predatory practices of private traders and discomfort that leaving maize to supply and demand market forces would be a national food security risk.

Decades of market domination by the NCPB left a relatively underdeveloped private sector grain trading capacity. No wonder, after maize marketing was liberalized in 1994 and the government pulled out there was such a vacuum in the market that producer prices plummeted by 50-70%, which was good for consumers but not producers. However, over the years, an increasing number of private traders have come into the market. They still complain of harassment by police, reminiscent of the previous controlled maize market era, but they are getting more engaged. But because of credit constraints and poor infrastructure, their ability to purchase and move more maize is constrained and, as a result, farmers are frustrated about the changes.

Specifically, in the 1998 maize harvest season, there was a serious lack of marketing outlets. There had been a flooding of the local maize market with imports just before the harvest season that severely depressed maize prices and farmers were unable to sell their produce. Local traders could not offer a better price and the government could not, due to budgetary constraints, step in and purchase surplus maize from farmers. The overall result was a huge loss for farmers, which caused many to consider reducing their production in the subsequent years, unless a long-term solution was found to what they saw as an emerging "perennial problem".

Karanja, Jayne and Strasberg (1999) found evidence that the process of maize market reforms may have reduced maize productivity by depressing producer prices and inflating input prices but Jayne and Argwings-Kodhek (1997) and Mukumbu and Jayne (1995) noted that the reforms conferred substantial benefits to consumers through lower consumer prices and maize processing costs. Therefore, the aggregate effects of maize market reforms need to be netted out between the gains to consumers and losses to producers. Such an analysis must consider that most of the Kenyan maize producers, particularly the small farmers, are also maize consumers.

Table 9 shows the per capita maize produced and consumed, the proportion of farmers who are net sellers and the proportion of maize sold, the average maize selling and purchasing prices and the market system preference shown by farmers. On average, large farmers produced 26 times more on per capita basis than small farmers, but this proportion varied by zone and region. Similarly, large farms consumed about 2.5 times more maize, on per capita basis, than small farmers. Looking at the difference between per capita production and consumption of maize, it is evident that only farmers in the high potential regions produced considerable surplus maize for sale. Most of the households in the marginal regions were net buyers of maize.

Table 9 also shows that fewer farmers sold their maize to the government marketing board, the NCPB, in 1998 compared to 1992 with only 3% of the farmers selling in 1998 compared to 19% in 1992. More small farmers (88%) sold to private traders compared to large farmers (71%). Most farmers sold their maize at harvest, when the selling price was low, and bought latter at a higher price. In fact, the average selling price in 1998 was Kshs.11.40 per Kg while the average purchase price was Kshs.15.05 per Kg, a differential of Kshs.3.65 per Kg or 32% of the selling price. Expectedly, maize prices were lower in the high potential regions compared to marginal regions, with the differential between producer and consumer prices being higher in the latter at Kshs.4.05 per Kg compared to the former at Kshs.3.21 per Kg.

Table 9: Per Capita Maize Production and Consumption, and Marketing by Farm Size and Zone

Parameter	Marginal Potential Zones				High Potential Zones		All Zones
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	
Per Capita Maize Production, Kg:							
Small Farm	105	91	141	59	203	343	181
Large Farm	128	83	208		9483	5952	4851
Per Capita Maize Consumption, 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
Prefers Current Market System (%):							
Small Farm	58	35	34	47	48	67	50
Large Farm	43	50	25	-	31	37	36

Generally, large farmers preferred the former marketing system before trade liberalization whereas small farmers showed no preference. Most farmers were dissatisfied with the low producer price at harvest time caused by large maize imports. Also, lack of on-farm storage facilities meant that they could not take advantage of the seasonal price fluctuations. Small farmers experienced problems under both systems, the major ones being delayed payments in the former system and lack of reputable markets in the current one.

CHAPTER 3

3.1 Impact of Technological Change

Estimating the relative poverty reduction potential of alternative research activities requires demographic assessment of who the users are, their locality, economic status, the types of income-generating activities, ways in which specific technologies affect their incomes and welfare, and how markets distribute output gains between different regions and households. Existing evidence on these issues is mixed (Renkow, 1993). Therefore, it is hard to justify any *a priori* rationale as a satisfactory basis for research investment without a thorough evaluation.

However, empirical evidence suggests that research costs are greater and the time lags are longer in achieving equivalent output gains in marginal areas compared to more favorable ones. For instance, in wheat and rice, genetic gains due to crop improvement for irrigated and high rainfall environments have tended to be higher on an annual basis than they have been in drier environments, and this difference is evident from experimental results to farmers' fields (Byerlee, 1996). Moreover, relatively more of the gains from research in marginal environments are likely to come from crop management research, which is more location-specific, but tend to be more costly than crop breeding research (Edmeades et al., 1998; Byerlee, 1994; Pingali and Heisey, 1999). However, if the bulk of past agricultural research investments have been made in favorable areas, incremental rate of return on investment may decline to the point where it competes with investments in marginal environments (Byerlee and Morris, 1993).

Empirical evidence is mixed concerning the welfare effects of improved technologies. Renkow (1993) found that investment in wheat research in favored, irrigated areas of Pakistan yielded greater overall income growth than investment in rainfed regions. In contrast, Fan and Hazell (1999) found that investment in improved technologies and rural infrastructure positively contributed to productivity growth and rural poverty reduction, with effects in rainfed marginal regions being greater than in high potential irrigated regions. Thus, in this case, public investments in the marginal regions had better returns, enhanced productivity growth and reduced poverty. These two examples, and others, indicate that one cannot generalize on the effects of technological change since they will tend to vary from country to country and region to region, and will depend on specific characteristics of the regions, technology and the economy.

Nevertheless, the impact of agricultural technology on poverty alleviation is a source of controversy. Proponents point to a large body of evidence showing that R&D has been instrumental in introducing agricultural innovations that have raised agricultural production, stimulated economic growth and helped poor people through lower food prices and higher incomes (Lipton and Longhurst, 1989). Evidently, agricultural technologies have helped food production grow faster than population growth, thus avoiding the widespread food shortages and catastrophe envisioned by Malthus (Plucknett, 1991). But there are concerns that research-led technological change in agriculture has favored wealthy farmers in high potential regions at the expense of the poor farmers and marginal regions (Freebairn, 1995).

Wealthy farmers are considered more likely to become "early adopters" of new technologies since they have better access to information and credit, and have more capacity to take risks. Similarly, some technologies may be too "lumpy" and may be profitable on large and not small farms. Benefits of such technology may also differ from one region to another. If it raises productivity in high potential regions but not in marginal regions, the increase in overall production may cause prices to fall, if in a closed economy, such that farmers in marginal regions are made worse off, thereby exacerbating poverty.

These competing effects of technological change can be demonstrated by considering a hypothetical example: supposing that an increase in agricultural productivity has four impacts: producers have higher output, labor suppliers receive higher wages and better employment, consumer prices fall and greater economic growth increases overall sales and employment. Consider also, as could be the case in Kenya, that producers are also consumers and providers of farm labor.

If technological change causes consumer prices to decrease, as would be the case in a typical closed economy, this means less income to producers but more disposable income to consumers. For people who are dual producers and consumers, whether they benefit from such technological change depends on which of the income effects is greater and whether they are net sellers or net buyers of that commodity. Moreover, the effect of rising wages on income will depend on whether they are net buyers or net sellers of labor. For instance, a net seller of labor and net buyer of food would gain unambiguously from a technology that lowers food price and raise wages. A technological change can raise incomes of adopting farmers but not of non-adopting farmers, change the demand for agricultural labor, reduce food prices or dampen food price increases and stimulate economic growth, thus, generating addition employment and increases in wages. The extent of these impacts on the overall economy vary greatly and depend on a variety of conditioning factors, such as the extent of adoption between regions, the indirect impact on prices of inputs, product and competing or alternative products, and the nature of markets and government interventions (Renkow, 1993).

Therefore, in evaluating the impact of technologies on farm welfare, the following variables are important: their direct impacts on output, input demand and input use; spillover effects mediated through product and labor markets that change relative prices; the relative numbers of different types of households within a particular region; the share of farm income in total household income and the nature of the market, whether in an open or closed economy. It is difficult, however, to state *a priori* which of these variables are the most important in determining the appropriateness of targeting one or the other type of production region. In Pakistan, it was agriculture's share of household income that appeared to exercise the dominant influence (Renkow, 1991). In Southeast Asia, labor mobility and the responsiveness of agricultural workers to perturbations in the labor markets were the key factors mediating the benefits of technological change (David and Otsuka, 1994).

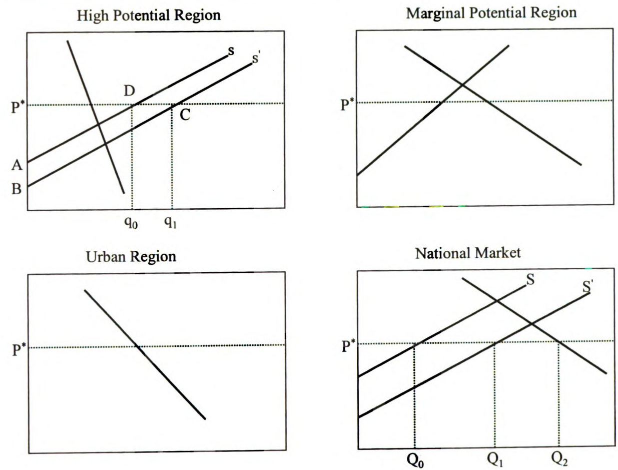
3.1.1 Partial Equilibrium Analysis of Technological Change

As discussed above, technological change can have variable effects on farm income both within and across regions, partly because farmers are a diverse population and will typically adopt the technology gradually and at times partially. Thus, depending on the rate and spread of adoption, the effects of technological change may be concentrated within a region or widespread. Further, the distributional implications for different farm households and regions will depend heavily on policies and institutions that condition the incentives and constraints that influence the adoption decisions (Mills, 1998). New technologies impact farm incomes and welfare through the product and input markets. But the extent and nature of such impacts depend also on whether the economy is closed or open, and whether the impact is restricted to one particular zone or spills over to other zones (Renkow, 1991).

3.1.2 Indirect Effects through Commodity Markets

To illustrate the nature of the market effects in a simplified partial equilibrium framework, consider a maize importing country that has a maize technology whose impact is limited to a maize net-exporting, high potential region and its marginal region is a net importer of maize. Figure 3 illustrates the impact of the technology, captured as a

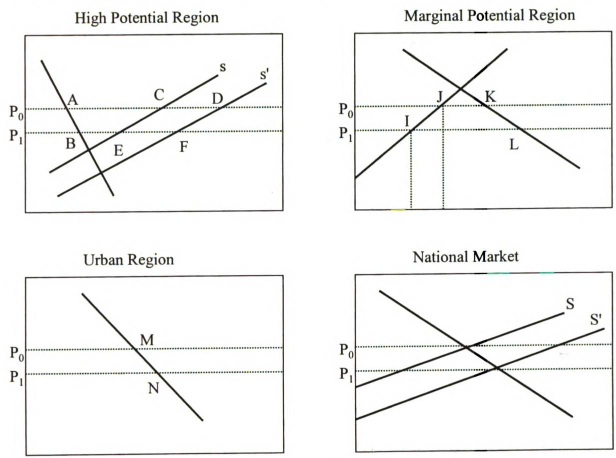
Figure 3: Fixed-Price Model of Technological Change



maize supply shift, on various regional maize markets in an open economy. The price of maize is determined exogenously and, thus, the expansion of maize supply from *s* to *s'* in the high potential region does not affect the maize price, such that producers in the region gain unambiguously from increased output at the same price, as depicted by the area ABCD. Producers and consumers in the marginal region experience no change in welfare since neither their production nor prices are altered. Urban consumers are likewise unaffected. At the national level, increased production in the high potential region shifts the supply curve from S to S', such that part of the national maize demand (Q_0Q_1) is met, and imports are reduced from Q_0Q_2 to Q_1Q_2.

In a closed economy, the domestic price is determined by the intersection of aggregate supply and aggregate demand. A shift in maize supply in the high potential region causes the aggregate maize supply to shift out from *s* to *s'*, in turn shifting the national maize supply from S to S' and accompanied by a decrease in price from P_0 to P_1 (Figure 4). Urban consumers gain unambiguously from the fall in price leading to an improvement in their welfare, represented by area P_0MNP_1. In the marginal region, the consumers gain (area P_0KLP_1) while the producers lose (area P_0JIP_1) from the decrease in maize prices, resulting in a net increase in total surplus equal to the area IJKL. In the high-potential region, like in the marginal and urban regions, consumers gain from lower maize prices but the impact on producers is indeterminate because the negative effect of falling prices is offset by an increase in output. The final results depend on the elasticities of supply and demand curves and the magnitude of the supply shift.

Figure 4: Flexible-Price Model of Technological Change

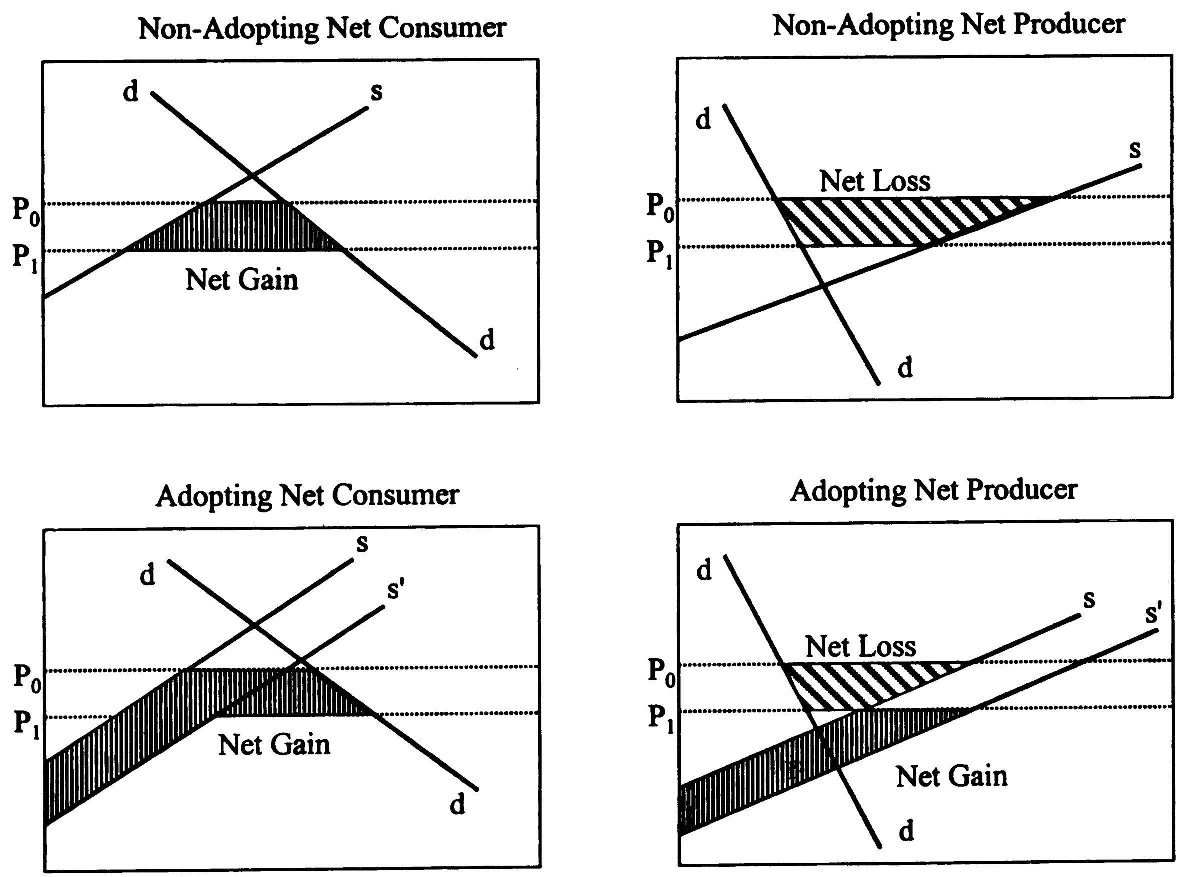


Such an analysis becomes complicated where, like in Kenya, producers are also consumers. In such a case, a change in price has both a positive and negative effect. A supply shift that causes a price drop reduces farm profits and cheapens food price at the same time, such that the net impact on welfare is determined by whether the household is a net producer or net consumer of maize. These different effects are depicted in Figure 5 for four types of households differentiated by whether they are adopters or non-adopters of the technology and whether they are net consumers or net producers.

It is evident that both adopting and non-adopting net consumers unambiguously gain from a fall in maize prices due to the supply shift caused by technological change. Net producers lose from the price decline but for those adopting the technology, the loss in welfare may or may not be fully compensated by productivity gain. For non-adopting net producers, there is no offsetting gain in productivity and, therefore, they suffer a net welfare loss. Net consumers in both urban and non-adopting marginal regions gain unambiguously from the price decline while non-adopting net producers in the latter unambiguously lose.

Clearly, the analysis may be further complicated if technology adoption is not uniform among household groups within a specific region, for example, if the technology is adopted more by large than small farmers in the high potential region. Differential adoption may be caused by information asymmetry, differential access to credit, extension or research, and differences in risk-taking. The effect may also be skewed by complementary inputs, infrastructure or information needed to adopt the new technology.

Figure 5: Technological Impact on Adopting and Non-Adopting Households



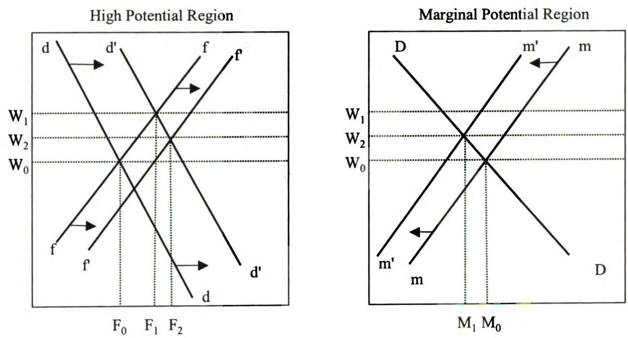
Skewed product preferences may also contribute to differential adoption patterns between different households in the same zone. For instance, small farmers focusing on home consumption may seek certain qualities in a maize variety (e.g. taste, storability) that commercial large farmers may have little interest on (Kumar, 1994).

3.1.4 Indirect Effects through Labor Market

There is substantial evidence that new, labor-using agricultural technologies tend to increase the demand for labor (Lipton and Longhurst, 1989; Renkow, 1993). Whenever labor supply is less than perfectly elastic, such changes in labor demand put upward pressure on wage rates in local labor markets, thus affecting incomes in technology-adopting regions, especially where agricultural labor is also a source of income. The effects on income may be transferred to the non-adopting region through rural-rural migration of workers if resultant real wages rise sufficiently to cover migration costs. Consequently, migration from the non-adopting region puts upward pressure on wages there as well, benefiting workers who remain behind.

Figure 6 illustrates these effects: initially, equilibrium wage, W_0, prevails in both high-potential and marginal regions. Adopting a new, labor-using technology in the high potential region shifts the labor demand from *d* to *d'* and raises the prevailing wage from W_0 to W_1. The difference in wage rates between the two regions induces migration from the non-adopting marginal region to the adopting high potential region. The influx of workers from the marginal regions shifts out labor supply in the high potential region

Figure 6: Impact of Technological Change on Labor Markets



from f to f', putting a downward pressure on wages there. On the other hand, the outflow of laborers from the marginal region puts upward pressure on the wage rate there due to a decrease or shift to the left of the labor supply curve from m to m'. This continues until a new equilibrium wage, W_2, is established.

Empirically though, there are instances where such effects may not be observed and wages may stagnate or experience only small changes. This happens where there is a high level of unemployment or underemployment in adopting areas and high population growth or migration into adopting areas. Another reason is that interregional migration is often costly and non-instantaneous. In the short run, labor tends to be immobile but fairly mobile in the long run if the wage differential is greater than the reservation wage and related transaction costs. Usually, the complex and dynamic nature of migration makes it hard to gauge the extent and direction of its contribution to the distribution of technological benefits.

3.1.4 The Role of Policies and Institutions

Use of farm inputs does not necessarily skew the gains from technological change if such inputs are adopted and used by all households. Problem arises when the market does not work well such that the supply is unreliable or when the inputs are targeted to one group of farmers and not the other, such that only one category of farmers have access to it and gain from it. The household's resource capacity is another factor influencing access. Most large farmers tend to be early adopters of new technologies because they have better access to extension and credit than small farmers have.

Lipton (1989) found many cases where early adopters gained and late adopters were made worse off, especially where economic policies related to input supply and land tenure favored one group of farmers more than another. He suggested that supportive policy reforms were necessary where technological change could be otherwise harmful. As agricultural economies evolve, market distortions have become an implicit means of skewing income distribution, quite often towards the large, wealthy farmers. A good example is the contentious agricultural subsidies in the United States and European Union, as well as past implicit tax support to large farmers in Kenya (BFWI, 2003; World Bank, 1995).

Often, governments in developing countries intervene in the agricultural sector through pricing policies and through public-sector investment projects. Policies affecting the prices of agricultural commodities are pervasive and can influence production, consumption, marketing or international trade. The policies may also be designed to generate government revenues, subsidize urban consumers, secure food self-sufficiency, earn foreign exchange, improve rural incomes or a combination of any of these. Often, the government is the principal provider of infrastructure and agricultural support services such as research and extension. Like pricing policies, such investments can be expected to have a strong impact on farm production, incomes and welfare of agricultural households.

Self-sufficiency in maize production has been an explicit policy objective of the Government of Kenya since the early 1960s. In order to ensure this objective is met, the government continued with the colonial policy, started in 1942, of using government-controlled cereal marketing boards to determine producer and consumer prices, to purchase and distribute maize grain, and import and export maize. Under the government-controlled regime, maize prices often fell within an export and import parity band regulated through maintaining a buffer stock (Pearson, 1992; Pinckney, 1988).

However, these maize policies changed dramatically in 1994 when the government, under pressure from donors and the Structural Adjustment Program of the International Monetary Fund (IMF), liberalized maize grain marketing in Kenya. Subsequently, the role of the marketing board, the National Cereals and Produce Board (NCPB) changed from complete domination of maize marketing to that of "custodian of strategic reserves and buyer of the last resort". In addition, maize price determination was left to market demand and supply forces and greater participation of private traders in maize marketing encouraged (Nyoro, Kiiru and Jayne, 1999.).

The details of specific agricultural policy changes and impacts between 1994-2002 are beyond the scope of this study. Many studies, including Omamo and Mose (2001), Karanja, Jayne and Strasberg (1999), Jayne and Mukumbu (1995) have investigated specific impacts of post-liberalized market policies. As a result, several pertinent issues related to the role of the government are worth noting. Firstly, the maize market reform in Kenya was characterized by an unfortunate back-and-forth policy reversal by the government that sent conflicting signals to producers and traders, and contributed to speculation and market uncertainty.

Secondly, there was little effort made to map out a clear reform process that ensured a smooth transition from a government-controlled to a market-controlled system and create of an enabling institutional framework and environment for such changes. Failure to establish such a process led to an institutional failure in maize marketing, which may have resulted in significant maize productivity and welfare losses (Karanja, Jayne and Strasberg, 1999). Lastly, there are serious institutional and infrastructure impediments to the benefits of market reforms, and these include public-funded rural infrastructure. Omamo (1998) and Renkow, Hallstrom and Karanja (2003) demonstrate how high transaction costs from poor roads and transport systems could hinder rural market participation and reduce gains from agricultural production.

In summary, government action or inaction affects the level and distribution of gains or losses to producers, consumers and the economy. Government interventions alter the range of distribution outcomes and serve to drive a wedge between consumer and producer prices (Renkow, 1991). The common tendency is to hold consumer prices below import parity and either subsidize or tax producers. In cases where both consumers and producers are subsidized, a shift in supply due to technological change represents a greater drain on public fiscal resources. But where price policies subsidize consumers and tax producers, as is often common, a supply shift increases the effective tax on producers and there is less drain on the government's fiscal resources.

When governments have substantial control over producer and consumer prices, as in Kenya before 1994, the prices may be regarded as fixed in the short run such that the supply shift is not accompanied by price changes. This is similar to the open economy scenario where the prices are set exogenously. In the long run, however, the prices change as a result of various things, which may include political pressure or government constraints. The government also has other intervention options that can influence the distribution of gains or losses from technological change that are beyond the discussion in this study. However, the next section outlines the analytical framework chosen for this study, which also includes assessment of the effects of potential government interventions.

3.2 The Multi-Market Model for Technological Change

3.2.1 The Analytical Framework

A multi-market model is used to analyze the impacts of maize technological change on farm incomes and their distribution in Kenya. The choice of the model is influenced by a need to evaluate the differential effects of the technologies among different types of households, some of which are net producers and others are net consumers, and in different regions. The model is implemented in six major maize growing regions and considers also an urban sector. In each maize growing region, the households are split into two groups, based on farm size: small and large. Production of two commodities is assumed, for simplicity, in each region, *r*; Q_1 is the output of maize, and Q_2 is the output of an alternative commodity.

Technology is modeled as an exogenous shift variable, *T*, labor (*L*) and fertilizer (*F*) are assumed the only variable inputs and land (*Z*) is considered a fixed input, at least in the short and medium term. Output supplies and input demands depend on the prices of the two commodities (P_1, P_2), the prices of the variable inputs, *W* and *f* for labor and fertilizer, respectively, and, except for Q_2, the technology shifter, *E*.

It is assumed that variable inputs are not differentiated by crop and that regional wage rates are endogenously determined in competitive labor markets, an assumption that is later dropped. The regional labor markets are assumed to clear in isolation due to labor immobility. The respective output supply and input demand equations, in rate-of-change notation, are represented by:

$$\hat{Q}_{1rh} = \varepsilon_{11rh}\hat{P}_1 + \varepsilon_{12rh}\hat{P}_2 + \varepsilon_{1Lrh}\hat{W} + \varepsilon_{1Frh}\hat{f} + \hat{E}_{1rh}$$

$$\hat{Q}_{2rh} = \varepsilon_{21rh}\hat{P}_1 + \varepsilon_{22rh}\hat{P}_2 + \varepsilon_{2Lrh}\hat{W} + \varepsilon_{2Frh}\hat{f}$$

$$\hat{L}^d_{rh} = \beta_{L1rh}\hat{P}_1 + \beta_{L2rh}\hat{P}_2 + \beta_{LLrh}\hat{W} + \beta_{LFrh}\hat{f} + \hat{E}_{Lrh}$$

$$\hat{F}_{rh} = \beta_{F1rh}\hat{P}_1 + \beta_{F2rh}\hat{P}_2 + \beta_{FLrh}\hat{W} + \beta_{FFrh}\hat{f} + \hat{E}_{Frh}$$

where the subscripts r and h denote region and household type, $i=1, 2; j=F,L;$ k=1,2,L,F; ε_{ikrh} and β_{jkrh} are region and household group specific elasticities of output i or input j with respect to price k, and $\hat{E}_{krh}$ is the exogenous proportional shift in output supply or input demand over time due to the new technology holding fixed inputs constant, and '^' implies "rate of change'. The changes in the total regional output are given by the sum of group-specific output changes weighted by each group's share of total regional output (λ_{irh}):

$$\hat{Q}_{1r} = \sum_h \lambda_{1rh}\hat{Q}_{1rh}; \hat{Q}_{2r} = \sum_h \lambda_{2rh}\hat{Q}_{2rh}$$

Likewise, changes in input demands are given by:

$$\hat{L}_r^d = \sum_h \delta_{rh}\hat{L}_{rh}^d; \text{ and } \hat{F}_r^d = \sum_h \Psi_{rh}\hat{F}_{rh}^d$$

where δ_{rh} and Ψ_{rh} are the shares of total regional demands for labor and fertilizer accounted for by household group h.

Individual rural labor supply, l_{rh}^s, is considered a function of real wage rate, $w = W/P_{rh}^*$, where P_{rh}^* is an endogenous, group-specific consumer price index. Denoting the population of household group h in region r as N_{rh}, group-specific labor supply is simply:

$$L^s_{rh} = l^s_{rh} \times N_{rh}$$

Letting ε_{Lrh} be the wage rate elasticity of household labor supply, proportional changes in regional labor supply are given by:

$$\hat{L}^s_{rh} = \varepsilon_{Lrh}\,\hat{w} + \hat{N}_{rh}$$

This can be aggregated to derive changes in regional labor supply as:

$$\hat{L}^s_r = \sum_h \psi_{rh}\,\hat{L}^s_{rh}$$

where ψ_{rh} is the share of labor supply in region r accounted by household group h. It is assumed that all residual farm profits not attributed to variable inputs accrue as returns to land. Therefore, letting Π_{rh} be farm profits of household group h in region r, then:

$$\Pi_{rh} = P_1 Q_{1rh} + P_2 Q_{2rh} - WL^d_{rh} - fF_{rh}$$

Changes in farm profits are, therefore, given by:

$$\hat{\Pi}_{rh} = \pi_{1rh}(\hat{P}_1 + \hat{Q}_{1rh}) + \pi_{2rh}(\hat{P}_2 + \hat{Q}_{2rh}) + \pi_{Lrh}(\hat{W} + \hat{L}^d_{rh}) + \pi_{Frh}(\hat{f} + \hat{F}_{rh})$$

where π_{irh} is group-specific profit shares accounted for by outputs and variable inputs (positive for outputs and negative for inputs). The household output demand, D_{irh} , is a function of the prices of these commodities and group-specific nominal income (Y_{rh}):

$$D_{irh} = D_{irh}(P_1, P_2, Y_{rh}) \qquad i = 1, 2$$

On the other hand, group-specific consumption, C_{irh}, is the product of household output demand and the group population growth in region *r*:

$$C_{irh} = D_{irh} \times N_{rh}$$

Group changes in consumption of both commodities are given by:

$$\hat{C}_{1rh} = \eta_{11rh}\hat{P}_1 + \eta_{12rh}\hat{P}_2 + \eta_{1Yrh}\hat{Y}_{rh} + \hat{N}_{rh}$$

$$\hat{C}_{2rh} = \eta_{21rh}\hat{P}_1 + \eta_{22rh}\hat{P}_2 + \eta_{2Yrh}\hat{Y}_{rh} + \hat{N}_{rh}$$

where η_{ijrh} is the group-specific cross-price elasticity of demand for commodity *i* with respect to the price of commodity *j*. Letting α_{krh} be the share of regional consumption of good *i* accounted for by group *h*, changes in regional consumption are:

$$\hat{C}_{ir} = \sum_i \alpha_{irh}\hat{C}_{irh} \qquad i = 1, 2$$

Group-specific nominal income within a region, Y_{rh}, is the sum of the net returns to factors rented out by that group. These factors included labor income, farm profits, and other exogenous sources (X) such as non-farm labor:

$$Y_{rh} = W\, L^{s}_{rh} + \Pi_{rh} + X_{rh}$$

Letting μ_{krh} denote the group-specific share of income attributed to income source k, where $k = L, \Pi, X$, and assuming no change in the distribution of land holdings, changes in real income ($y = Y/P^{*}_{rh}$) are given by:

$$\hat{y}_{rh} = \mu_{Lrh}(\hat{W} + \hat{L}^{s}_{rh}) + \mu_{\Pi rh}\hat{\Pi}_{rh} + \mu_{X}\hat{X}_{rh} - \hat{P}^{*}_{rh}$$

where P^{*}_{rh} is a region/group-specific consumer price index. Changes in this price index are given by

$$\hat{P}^{*}_{rh} = \sum_{i} \omega_{irh}\hat{P}_{irh} \qquad i = 1, 2$$

where ω_{irh} is the group-specific expenditure share for commodity k.

3.2.2 Closing the Model and Simulation Scenarios

Closing the model requires specification of the conditions under which maize and labor markets clear. Table 10 summarizes the basic characteristics of two sets of analyses done in this study. The first is a fixed-price model, in which maize prices are exogenous and labor is assumed mobile so that it clears nationally. In addition, imports are endogenous and are used to bridge the gap between national demand and domestic production. This closely represents the pre-1994 period in which the government set both producer and consumer prices of maize according to its desired price policy. Alternatively, this may also happen when the world market determines the maize prices.

The second represents a flexible-price model in which domestic maize prices are determined endogenously by demand and supply conditions, similar to a closed economy. Labor is, as in the previous model, considered mobile so that it clears at the national level. However, this model is set up to allow some potential influence by the government through exogenous imports, presumably as part of its trade policy. Therefore, this closely matches the current system in which the maize market is liberalized with respect to internal trade and the government covertly influences maize trade by indirectly sanctioning large maize imports that often depresses maize price at harvest time.

Table 10: Multi-Market Model Characteristics

Parameter	Fixed-Price Model	Flexible-Price Economy
Maize Market	Open	Closed
Maize Price	Exogenous	Endogenous
Regional Labor Market	Integrated	Integrated
Maize Imports	Endogenous	Exogenous

These two models assess long-run impacts of technological change and, thus, assume that labor markets are sufficiently integrated to allow wages to clear and be determined at the national level.[8] The labor market clearing condition is represented by:

$$\sum_r \frac{L_r^d}{L}\hat{L}_r^d = \sum_r \frac{L_r^s}{L}\hat{L}_r^s$$

The maize market clearing condition for the two models is based on the identity $C_1 = Q_1 + G$, where C_1 is the total national consumption, Q_1 is the total national production, and G is the quantity of government-influenced maize imports. In the fixed-price model, G is endogenous and makes up the difference between production and consumption, either through net imports or alteration of government buffer stocks whereas in the flexible-price model, G is exogenous. Therefore, the rate-of-change notation, the identity becomes:

$$\sum_r \frac{C_{1r}}{C_1}\hat{C}_{1r} = (1-\Gamma)\sum_r \frac{Q_{1r}}{Q_1}\hat{Q}_{1r} + \Gamma\hat{G}$$

where $\Gamma = G/C_1$ is the share of imports in the national consumption. Second-round effects are not estimated for any of the models

[8] However, this ignores transaction costs of moving from one region to another.

3.3 Parameter Selection and Share Computations

3.3.1 Production and Consumption Shares

Inter-regional production shares are computed using the 1996-98 data on area and maize production from the Department of Remote Sensing and Resource Surveys while intra-regional production shares are computed using the following formula and the1998 farm survey:

$$\frac{Q_i}{Q} = \frac{a_i w_i y_i}{\sum_i a_i w_i y_i}$$

where Q_i=maize output for household *i*, Q=maize output in maize zone, a_i=share of total cropped area farmed by the household *i*, w_i=share of maize in total cropped area for household *i* and y_i=ratio of average yield for household *i* to the average yield in the maize zone. The data was transformed from district to zonal data using a GIS classification template developed by KARI (Mills, 1998).

Table 11 presents the production and consumption shares of maize and the alternate commodity by zone and household type. The alternative crops were selected based on farmers' preferences and corroborated by regional crop production data and assessment from Kenya's agricultural extension offices. Farmers in the Lowlands zone chose cassava as their most prominent alternative crop to maize. The zone accounted for nearly 30% of Kenya's cassava or about 140,000 Mt between 1996-98. The crop was also the alternative crop chosen by farmers in the non-urban Rest of Kenya (ROK) zone, although it accounted for a small fraction of the national total production.

Table 11: Production, Consumption, Input Demand and Population Shares Used in the Simulations

Parameter	Marginal Potential Zones				High Potential Zones	
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands
Maize Production (Consumption) Shares[a] (% of national total)						
• Small Farms	0.5 (2.2)	3.3 (6.9)	9.1 (11.7)	3.9 (3.8)	13.6 (17.8)	16.8 (13.0)
• Large Farms	0.7 (0.7)	4.4 (4.6)	5.8 (2.0)	0.5 (0.7)	27.1 (4.5)	11.2 (3.3)
Non-Maize Production (Consumption) Shares[b] (% of national total)						
• Alternative Crop Choice	Cassava	Dry Beans	Millet	Wheat	Wheat	Wheat
• Small Farms	27.0 (18.0)	19.8 (17.9)	31.0 (18.2)	4.2 (0.8)	4.8 (7.3)	15.6 (4.7)
• Large Farms	0.6 (6.0)	2.2 (4.5)	0.6 (4.6)	15.0 (2.0)	16.1 (11.0)	36.4 (7.0)
Labor Demand (Supply) Shares[b] (% of total)						
• Small Farms	2.1 (4.9)	13.4 (15.1)	12.4 (15.1)	9.1 (5.6)	17.0 (24.8)	13.5 (13.9)
• Large Farms	1.9 (1.1)	9.6 (3.9)	6.6 (1.1)	0.6 (1.3)	5.0 (4.5)	2.2 (4.6)
Fertilizer Demand Shares[b] (% of total fertilizer demand)						
• Small Farms	0.0%	4.5%	3.9%	5.4%	17.7%	13.6%
• Large Farms	0.0%	9.5%	3.9%	0.7%	28.6%	9.2%
Population Shares[c] (% of total)						
• Small Farms	3.4%	11.9%	11.9%	4.5%	19.4%	11.2%
• Large Farms	0.7%	2.7%	1.1%	0.9%	3.2%	3.6%

Source: [a] Kenya (1999); [b] Karanja (1999); [c] Author's Compilation: represents population in marginal and high potential regions, and leaves out non-maize ROK zone (5.2%) and urban regions (22%).

The alternative crop in the Dry Midaltitude zone was dry beans. This zone accounted for 22% of the country's total dry beans production. Farmers in the Moist Midaltitude chose millet as their alternate crop and the zone accounted for about one-third of the total millet production. Wheat was the choice in the Dry Transition, Moist Transition and Highland zones, with data indicating that large farmers in these zones produced nearly 70% of all of Kenya's wheat. The choice was maintained for small farmers as well since their crop choices, potatoes and beans, which are intercropped with maize on small areas rather than substitute for maize.

Maize consumption shares were computed from zonal population estimates and the KMIS consumption data. First, the population was transformed from district to zonal data and the average per capita consumption values from the farm survey data used to estimate the share of maize consumption by zone and household. For the urban households, the average national per capita consumption level was used. A similar procedure was used to compute consumption shares for alternate crops.

The results indicated that most of the maize was consumed on-farm by small farmers while large farmers, mostly in high potential regions, accounted for large marketable surpluses. Comparison of production and consumption shares reveal that in the marginal region only large farmers in the Moist Midaltitude zone were net producers of maize; the rest were net consumers. In the high potential region, only small farmers in Moist Transition zone were net consumers; the rest were net producers. At aggregated zonal level, only the Moist Transition and the Highland zones were net exporters of maize, the rest had varying degrees of maize insufficiency. For instance, the Lowland zone met only 32% of their maize consumption needs; Dry Midaltitude (52%), Moist Midaltitude (84%), Dry Transition (76%) and ROK (54%). In general, Kenya had a maize deficit of 22%, a wheat deficit of 39% but was self-sufficient in sorghum, millets and dry beans over the period 1996-98.

3.3.2 Input Demand, Input Supply and Population Shares

Table 11 also tabulates shares of labor and fertilizer demand, labor supply and population. Labor demands were computed from farm level data and aggregated to household and zone levels. Small farms demanded about 70% of total labor and 48% of total fertilizer used on maize. Farmers in marginal regions demanded approximately 60% of the total labor and only 30% of fertilizers. This may be due to a higher labor-intensity of maize technology for marginal regions. In contrast, the high potential regions demanded 70% of fertilizer and 38% of total labor for maize production. The two high potential zones and the Lowland zone had surplus labor while the rest experienced deficits.

Labor supply shares were computed from population census and distribution of agricultural households reported in Kenya (1994). Since supply of farm labor for maize production from the landless and large farms is rare in rural areas, it was assumed that all hired labor comes from small farms. The assumption was supported by lack of significant labor flows between villages. In general, family labor accounted for 82% of all labor supply for maize production, with the proportion being higher among small farms (87%) than among large farms (73%). Population shares showed that 78% of the population lived in rural areas in 1998, about half of it the high potential regions and the other half in the vast marginal regions.

3.3.3 Income, Profit and Expenditure Shares

Table 12 presents profit, income and expenditure shares by zones and household type. Income shares were computed from farm production, sale of agricultural labor and non-agricultural activities, reflecting the relative contribution to household income. Farm profits for the major agricultural production activities, namely the production of maize, alternate crops and other crops/livestock, were derived by subtracting total inputs cost from revenues accruing to these activities. Profit shares were then computed as the proportion of revenue accruing to these activities, with profit shares of farm inputs recorded as negative profit.[9]

Maize production accounts for over one third of the total household profits in all farms in the Moist Midaltitude and Moist Transitional zones, among large farms in the Lowlands zone and small farms in the Highlands zone. Overall, profits from maize production are particularly important in small and large farm households in the high potential regions, and are a relatively insignificant fraction of total household income for small farms in the Lowlands zone (7%) and large farms in the Dry Transition zone (9%).

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[9] Family labor's reservation wage was assumed to be half the hired labor rate.

Table 12: Profit, Income and Expenditure Shares Used in Simulations

Parameter	Marginal Potential Zones				High Potential Zones	
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands
Maize Profit Shares[a] **(% 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[a] **(% 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[a] **(% 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%

Source: [a] Karanja (1999); [b] Kenya (1994)

The importance of farm income to total household income, as is the share of maize profits in farm profits, varies widely across zones and farm types. But still, farm profits are the major source of income for all households except in the Lowlands zone and among small farms in the Moist Transition zone (about 40%). Among large farms in the high potential zones, farm profits accounted for over 90% of total household income. In addition to farm profits, small farm households, especially in marginal regions, obtain a sizable fraction of household income from returns to farm labor, with zonal levels ranging from 6-9% in the high potential regions and 10-21% in the marginal regions. Thus, factors that affect agricultural wage rates, such as shifts in labor demand attributable to diffusion of new technologies, may have important impacts on the welfare of these households.

Overall, 62% of the rural households' income comes from farm production, 28% from non-farm activities and 10% from sale of agricultural labor. These proportions vary between high potential and marginal regions. In the marginal regions, farm profits account for 56% compared to 79% in high potential regions. Similarly, off-farm activities and sale of agricultural labor account for 32% and 12% of household income in marginal areas while the accounting for 17% and 4%, respectively, in high potential regions. Thus, *ceteris paribus*, an increase in the profitability of maize production from technological diffusion will invariably affect more strongly those households in which maize profits represent a large share of household income.

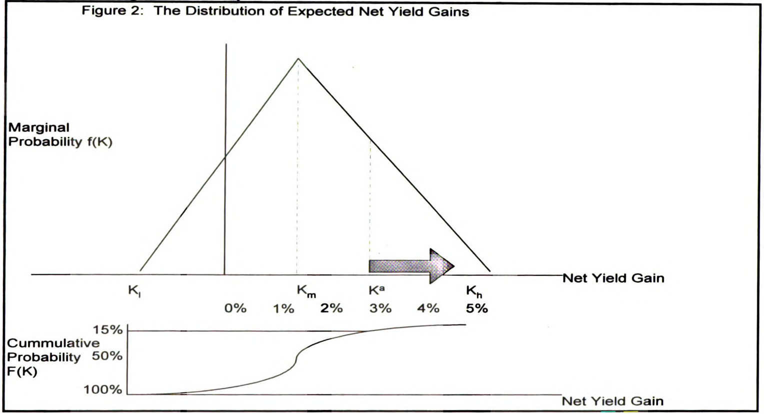
Expenditure shares were estimated from the 1994 Kenya Welfare Monitoring Survey data, which had detailed food and non-food consumption expenditure data and used a similar same sampling frame as this study. For simplicity, household food and non-food preferences were assumed not to have changed significantly between 1994-98, and if they did, the changes were assumed to have occurred proportionately across zones and households. On average, maize accounted for 19% of the total household expenditures, including for urban households. There was significant inter- and intra-zonal variation, with the largest expenditure shares being in large farms in the Lowland zone (47%) and in the Dry Transition zone (50%). Households with the largest maize expenditure shares would be affected the most if there is a huge price change caused by technological shift.

3.3.4 Maize Technology Shifter

Mills (1998) estimated the measure of technology shift used in this study as two distinct processes: (1) technology development; and (2) technology adoption. The technology development process is viewed as a triangular distribution of possible yield gains or losses, adjusted for incremental input use or savings, to generate the expected net yield gain, which was computed from: (1) the probability of exceeding the net yield gain dissemination threshold; and (2) the expected net increase conditional on the dissemination threshold being exceeded.

Figure 7 depicts the distribution of expected net yield gains. Letting K represent the net yield gain of an innovation, the minimum net yield gain is K_l, the most probable net yield gain is K_m and the maximum net yield gain is K_h. The minimum net yield gain necessary for an innovation to be released for dissemination is K^a, (a 3% gain in this example). For

Figure 7: Modeling the Probability Distribution of Research Outcomes



Source: Mills (1998)

every K there is a corresponding probability f(K) which is assumed to follow a triangular probability distribution. The probability of achieving K^a, $Pr(K \geq K^a)$, is given by the cumulative density function. In the example, the probability of a net yield gain from research above 3% is quite low, approximately 15%. The expected net yield gain is simply the expected value of K, conditional on K^a being achieved: $E[K|K \geq K^a]$.

For a triangular probability density function the cumulative probability of producing an innovation with a net yield gain above K* is:

$$Pr(K \geq K^*) = 1 - \frac{(k^* - k_l)^2}{(k_h - k_l)(k_m - k_l)} \text{ if } k_l \leq k^* < k_m \text{ and}$$

$$Pr(K \geq K^*) = \frac{(k_h - k^*)^2}{(k_h - k_l)(k_h - k_m)} \text{ if } k_m \leq k^* < k_h .$$

The expected net yield gain, E[K], given the threshold value for dissemination is reached can be calculated as:

$$E[K|K \geq K^*] = \frac{\left[\left(\frac{2}{(K_h - K_l)(K_m - K_l)}\right)(1/3K^3 - 1/2K^2K_l)\right]_{K^*}^{K_m} + \left[\left(\frac{2}{(K_h - K_l)(Kh - Km)}\right)(1/2K^2K_h - 1/3K^3)\right]_{K_m}^{K_h}}{\left[\frac{2}{(K_h - K_l)(K_m - K_l)}(1/2K^2 - K_l)\right]_{K^*}^{K_m} + \left[\frac{2}{(K_h - K_l)(K_h - K_m)}(K_h - 1/2K^2)\right]_{K_m}^{K_h}}$$

For $K_l \leq K^* < K_m$ and

$$E[K|K \geq K^*] = \frac{\left[\left(\frac{2}{(K_h - K_l)(Kh - Km)}\right)(1/2K^2K_h - 1/3K^3)\right]_{K^*}^{K_h}}{\left[\frac{2}{(K_h - K_l)(K_h - K_m)}(K_h - 1/2K^2)\right]_{K^*}^{K_h}}$$

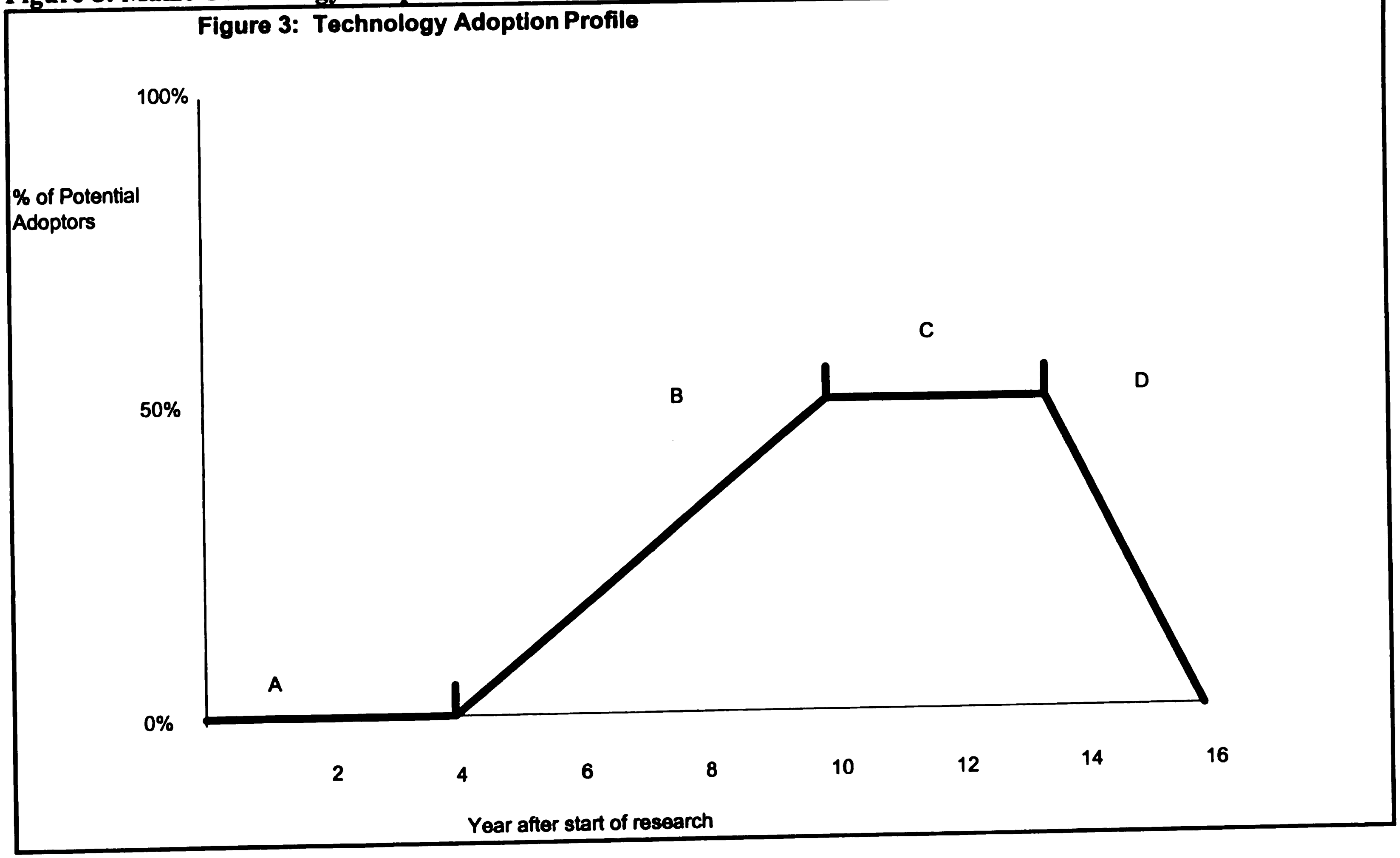
For $K_m \leq K^* < K_h$.

This net yield gain is contingent upon the rate and extent of technology adoption. Therefore, the adoption profile is estimated using a simple, linear approximation, represented by Figure 8. The profile is envisaged having a trapezoidal functional form with a: research development phase (A); increasing adoption phase (B); adoption plateau phase (C); and a declining adoption rate phase (D).

The final adjusted net yield gain is the product of the estimated probability of dissemination and the conditional expected net yield gain. Table 13 presents results of this analysis, with net yield gains presented in percentage form, and generated by research themes - breeding, crop management and technology transfer - and by zones used in this study. The net yield gains are summed up across the themes to generate an estimate of a maize supply shift used in the model simulations. This shift ranges from about 7% in the Lowlands zone to about 30% in the Moist Transition zone.

The projected yield improvement in marginal regions is largely attributed to change in crop management practices, whereas breeding research has greatest relative impact the high potential regions. The implications of this is that labor demand due to technological change is higher in the marginal regions (11%) and lower in the high potential region (6%), since agronomic innovations are more labor intensive. Estimated fertilizer demand associated with technology adoption in both marginal and high potential regions is not significantly different because the former hardly use any fertilizer while the latter will probably use just as much as their former levels.

Figure 8: Maize Technology Adoption Profile



Source: Mills (1998)

Table 13: Net Yield Gains and Input Demands Associated with Zone-Specific Technologies

Zone	Source of yield gains (%)			Net Yield Gain	Labor Demand Increase[1]	Fertilizer Demand Increase[1]
	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%

Source: Mills, Hassan and Mwangi (1995); [1] Author's compilation.

3.3.5 Elasticities and Model Structure

The elasticities used in the modeling in this study (Table 14) indicate behavioral response of households to changes in product and input prices that they face as consumers, producers or suppliers of labor. Because elasticities for this study could not be estimated from primary data, the necessary elasticities were borrowed from other studies. Munyi (2000) used time series data (partially used in this study) to estimate output supply and input demand elasticities for different maize production regions in Kenya. Labor and fertilizer supply elasticities were borrowed from Pitt and Sumodiningrat (1999), and consumption demand elasticities adapted from Renkow (1991).

Once all the parameters are assembled, each of the multi-market models is constructed in the form **HU** = **K**, where **H** is a matrix of elasticities and shares, **U** is a vector of "unknown" endogenous variables (including proportionate changes in production and consumption of maize and non-maize commodities, input demand and supply, consumer price index, wage rate, real income, farm profits and maize price (in flexible-price model) or maize import (in fixed-price model) for each region and group), and **K** is a vector of exogenous variables (including proportionate changes in the technology shifter, population, fertilizer price, price of non-maize crop, exogenous income, price of maize (in fixed-price model) and maize import (in flexible-price model). Pre-multiplying both sides of the equation by the inverse of matrix **H** yields a solution for **U** for specified values of exogenous variables in **K**. Figure 9 illustrates the structure of the multi-market models, using arrows to show links between various components in the model.

Table 14: Selected Elasticities Used in Model Simulations

Zone	Maize supply elasticity *(own price)*	Maize supply elasticity *(cross-price)*	Maize supply elasticity w.r.t. labor price	Maize supply elasticity w.r.t. fert price	Demand elasticity of maize wrt maize prices	Demand elasticity of maize w.r.t. to income
Lowlands	0.199	-0.085	-0.050	-0.150	-0.400	0.260
Dry Midaltitude	0.399	-0.060	-0.050	-0.150	-0.400	0.260
Moist Midaltitude	0.305	-0.085	-0.060	-0.200	-0.450	0.260
Dry Transition	0.338	-0.179	-0.060	-0.200	-0.450	0.260
Moist Transition	0.378	0.014	-0.080	-0.250	-0.500	0.200
Highlands	0.326	-0.092	-0.080	-0.250	-0.500	0.200
Urban	-	-	-	-	-0.550	0.350

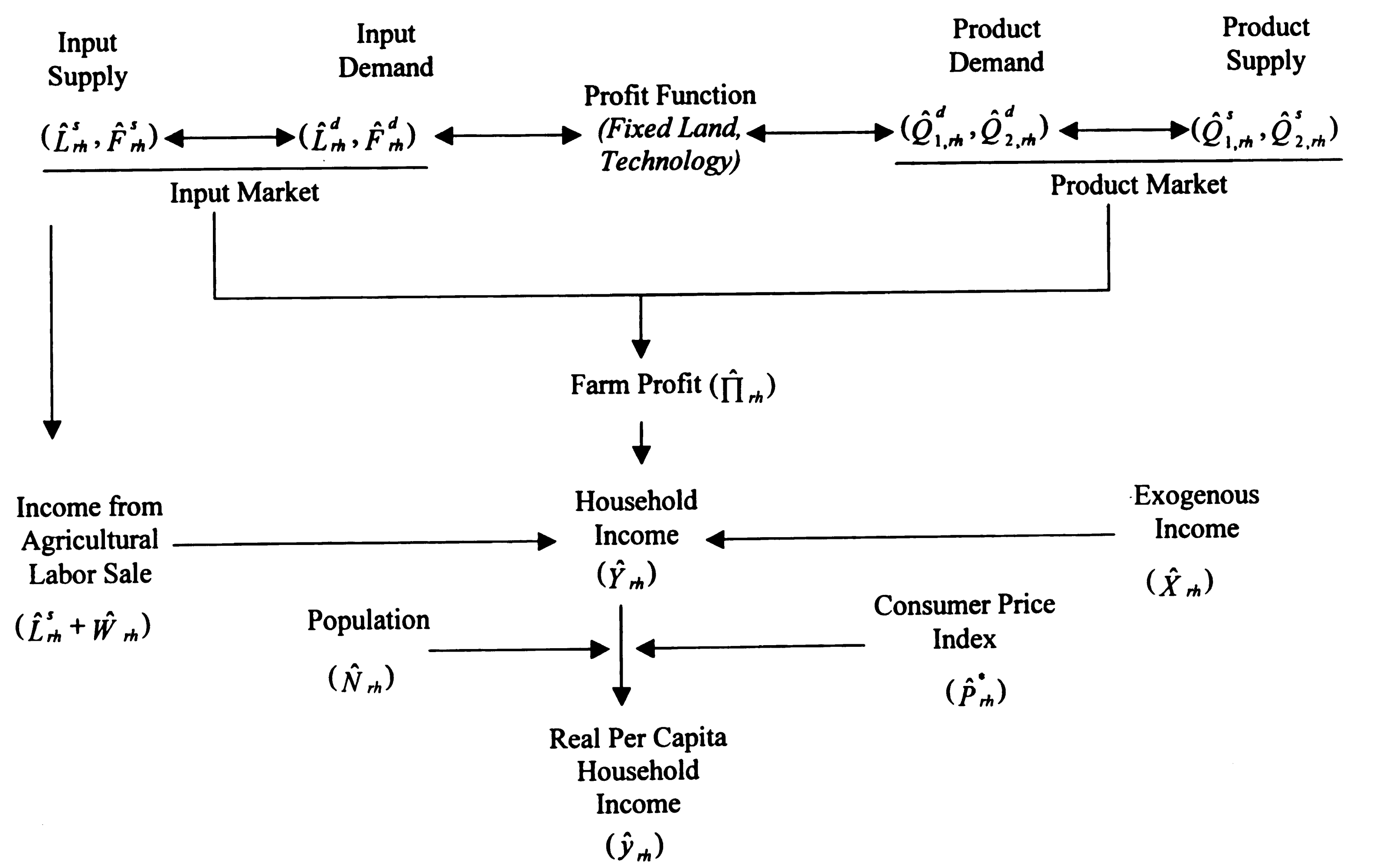
Source: Munyi (2000), Pitt and Sumodiningrat (1991).

Table 14 (Contd.)

Zone	Labor demand elasticity w.r.t. labor price	Labor demand elasticity w.r.t. maize price	Labor demand elasticity w.r.t. fert price	Labor demand elasticity w.r.t. altcrop price	Fertilizer demand elasticity w.r.t. maize price	Fertilizer demand elasticity w.r.t. altcrop price	Labor supply elasticity
Lowlands	-0.35	0.020	-0.030	0.050	0.050	0.030	0.400
Dry Midaltitude	-0.35	0.020	-0.030	0.050	0.050	0.030	0.400
Moist Midaltitude	-0.35	0.020	-0.030	0.050	0.050	0.030	0.400
Dry Transition	-0.35	0.020	-0.030	0.050	0.050	0.030	0.400
Moist Transition	-0.45	0.030	-0.080	0.030	0.100	0.130	0.500
Highlands	-0.45	0.030	-0.080	0.030	0.100	0.130	0.500
Urban	-	-	-	-	-	-	-

Source: Pitt and Sumodiningrat (1991), Renkow (1991).

Figure 9: Multi-Market Model Structure



CHAPTER 4

4.1 Results and Discussions from Simulations

The multi-market model framework was used to simulate the impact of an exogenous shock caused by maize technological change on farm profits and income, with the latter being used as a measure of farm welfare. Two models are estimated: (1) a fixed-price model and (2) a flexible-price model.[10] For each model, three scenarios are simulated:

1. When technology diffusion is limited to the marginal regions;
2. When technology diffusion is limited to the high potential regions; and
3. When technology diffusion occurs in both the marginal and high potential regions.

The results of each model are compared to a baseline scenario, which assumes no technological change in any of the regions but an annual growth in exogenous income by 2.3% and population by 3.1% (Kenya, 1994).[11] A further comparison is made in the fixed-price model by assuming maize prices increase exogenously by 20%, which is consistent to fluctuation in domestic and world market prices as shown in Figure 10 and Figure 11, respectively. In the flexible-price model, comparison is made to when maize imports are doubled exogenously. In general, all the simulations assume no change in market institutional structure, so that marketing margins remain constant and there are equal changes in producer and consumer maize prices.

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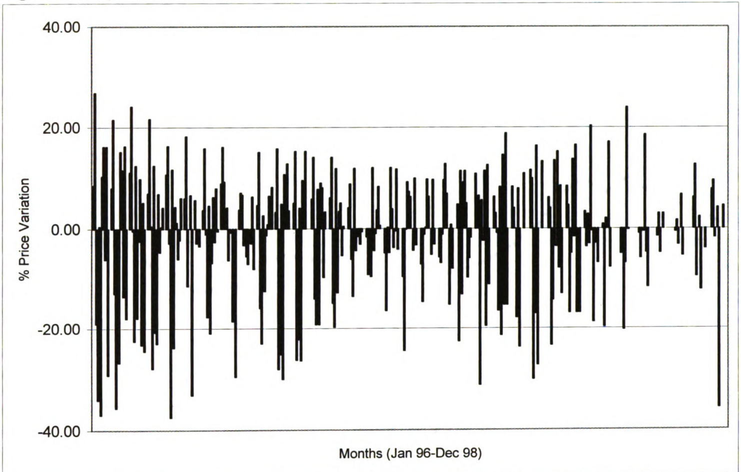
[10] Both models estimate long-run scenarios in which labor is mobile and labor markets clear nationally.

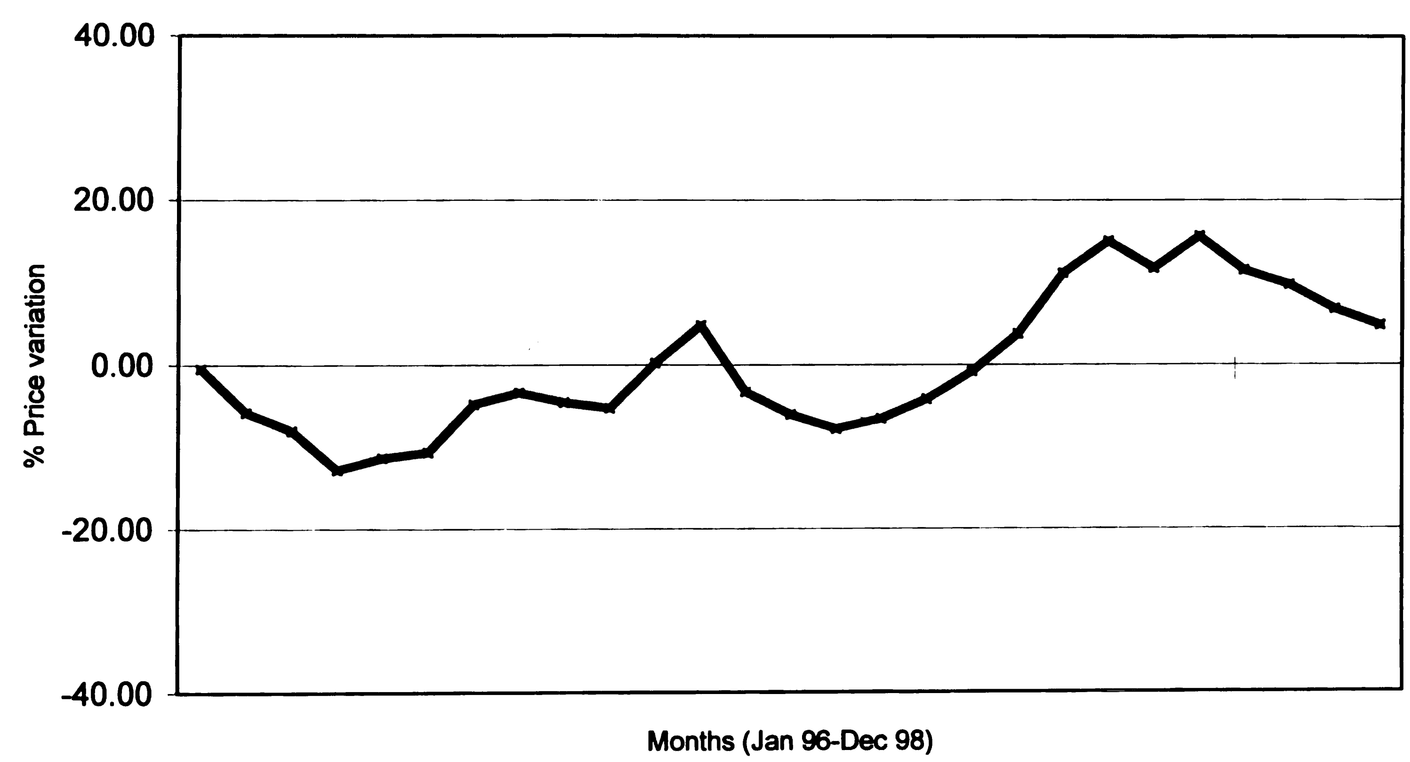
[11] A 15-year period, starting 1998, is considered for this analysis.

Figure 10: Kenya Domestic Maize Price Variation, Jan 1996 - Dec 1998*



* Measures maize price variation in several domestic markets.

Figure 11: World Market Maize Price Variation, Jan 1996 - Dec 1998[*]



[*] F.o.b. (Mombasa), white corn price

4.1.1 Fixed-Price Model Simulations

The results of simulations under the fixed-price model are presented in Tables 15a-f. Table 15a presents results of the baseline scenario, which indicates a general decline in real income for all households in the absence of technological change and change in maize prices. An increase in population growth stimulates growth in labor supply, which puts a downward pressure on wages in turn causing growth in aggregate farm profits. But as population growth dominates exogenous household income growth, real per capita income of all households, including urban households, decline. Real agricultural wages decline by 60% and maize import demand increases by 165% over current levels (1998). The national maize production level (weighted by zonal output shares) increases by only 4.3% while the aggregate real income decline by 36% over the current level. Evidently, this is not a sustainable option for Kenya.

Table 15b presents results of the simulation when technology diffusion occurs in the marginal regions. Maize production increases in the marginal regions, relative to the baseline, as a result of technology adoption there. Overall, national maize production increases by 4.1%, resulting in a decline in maize import demand by 15% compared to the baseline scenario. In addition, increasing maize production in marginal regions raises labor demand and puts upward pressure on the real agricultural wage, which increases by 6.8% relative to the baseline case.

Table 15a: Fixed Price Model Results: Baseline Scenario[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones			
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands	Urban	National
Maize production	2.96	2.96	3.55	3.55	4.73	4.73		4.33
Farm profits[2]								
▪ Small farms	**3.30**	**4.95**	**5.63**	**5.34**	**6.25**	**7.47**		**4.41**
▪ Returns to Land	6.31	16.39	21.65	16.53	11.63	10.09		10.69
▪ Large farms	**4.02**	**5.12**	**6.84**	**5.01**	**6.62**	**7.09**		
▪ Returns to Land	13.86	12.65	28.56	11.82	7.92	7.95		
Real Income per capita								
▪ Small farms	-41.45	-51.84	-42.16	-59.32	-45.46	-59.24		-37.40
▪ Large farms	-36.99	-52.12	-31.47	-59.58	-53.76	-63.10		
▪ Urban households							-36.27	
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								-59.15
General Price Index								0.00
Imports								164.78

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes in which no technological change takes place and growth in population and exogenous income follow recent patterns.

[2] Bold figures represent combined returns to land and family labor.

Table 15b: Fixed Price Model Results: Technological Change in Marginal Regions[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	7.05	12.65	13.99	27.83	-0.54	-0.54		4.11
Farm profits[2]								
▪ Small farms	**-0.25**	**2.28**	**5.78**	**8.42**	**0.77**	**-0.81**		**1.49**
▪ Returns to Land	-1.29	-3.15	0.25	3.29	-1.33	-1.15		-0.77
▪ Large farms	**1.53**	**2.00**	**5.43**	**2.67**	**-0.40**	**-0.80**		
▪ Returns to Land	-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		0.30
▪ 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

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to the baseline scenario (Table 15a).
[2] Bold figures represent combined returns to land and family labor.

Changes in farm profits for the different household groups are influenced by whether they are technology adopters and the labor-intensity of their maize farming.[12] Therefore, for adopters, farm profits increase or decrease depending on which is dominant between the positive effects of productivity gains from adopting new technology or the negative effects of increasing cost of production from higher wages caused by adoption of new, labor-inducing technology. Table 15b shows that, apart from small farm households in the Lowlands zone whose productivity gain is insufficient to compensate for increased labor costs, all households in marginal regions experience gains in farm profits. For non-adopting households in high potential regions, increasing cost of labor without a corresponding productivity gain leads to a decline in farm profits, except for smallholder households in the Moist Transition zone.

Changes in real household income are influenced by changes in labor wages and farm profits, and the relative importance of these components in the household income (Figure 10). Apart from small households in the Moist Transition zone, for whom labor earnings are an important source of household labor, households in high potential regions suffer declines in real per capita incomes, again primarily because of higher labor costs without productivity gains from technological change. In the marginal regions, all households except small farmers in Dry Midaltitude and large farmers in Moist Midaltitude zones, experience gains in real per capita incomes. Real per capita income for urban households remains unchanged since maize prices do not change. Overall, aggregate farm profits, which are computed as the sum of farm profits for all households weighted by zonal

[12] Farm profits refer to combined returns to land and family labor.

population share, increase by 1.5% while aggregate real income, computed as the sum of real income for all households weighted by zonal population share, increase by 0.3%.

Table 15c shows the impact of maize technology when it is limited to high potential regions. Weighted national maize production increased by about 15%, compared to 4.1 for marginal regions. All adopting households in high potential regions enjoyed higher farm profits accruing from large output effects, which overcome induced labor costs. All non-adopting households in marginal regions suffer declining profits since their labor costs increase as wages rise by 2%, without any productivity gain. This wage effect is smaller than when the technology diffusion takes place in the marginal regions (6.8%) because marginal regions' technologies are more labor demanding (Table 13).

Demand for maize imports declines by 50%, relative to the baseline, compared to a decline of 15% for the marginal region scenario (Table 15b). The aggregate farm profits for the high potential region scenario (2.9%) is almost double that of the marginal region scenario (1.5%). The aggregate income increased by 1.8% compared to the baseline scenario, compared to 0.3% when the technology diffusion occurs only in the marginal region.

Table 15d shows simulation results when technology diffusion occurs in both marginal and high potential regions. The overall impact on the weighted maize production is greater, raising national production by about 19%, than when the technology is limited to either of the regions. This puts upward pressure on real agricultural wages, which rise by

Table 15c. Fixed Price Model Results: Technological Change in Highland Regions[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	-0.10	-0.10	-0.12	-0.12	29.54	8.64		14.87
Farm profits[2]								
▪ Small farms	**-0.11**	**-0.17**	**-0.19**	**-0.18**	**11.49**	**2.57**		**2.89**
▪ Returns to Land	-0.22	-0.56	-0.74	-0.57	10.86	2.08		
▪ Large farms	**-0.14**	**-0.18**	**-0.23**	**-0.17**	**11.85**	**1.69**		**2.55**
▪ Returns to Land	-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		1.84
▪ 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

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to the baseline scenario (Table 15a).

[2] Bold figures represent combined returns to land and family labor.

Table 15d. Fixed Price Model Results: Technological Change in All Regions[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	6.95	12.55	13.87	27.71	29.00	8.10		18.99
Farm profits[2]								
▪ Small farms	**-0.17**	**2.11**	**6.59**	**8.24**	**12.25**	**3.05**		**4.69**
▪ Returns to Land	-1.50	-3.27	-0.49	2.72	9.53	0.93		1.78
▪ Large farms	**2.01**	**1.83**	**6.56**	**2.50**	**11.45**	**1.32**		
▪ Returns to Land	-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		2.17
▪ 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

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to the baseline scenario (Table 15a).

[2] Bold figures represent combined returns to land and family labor.

8.8%, relative to the baseline scenario. The increase in maize production from both regions depresses maize import demand by about 64%, compared to 15% for marginal regions and 50% for high potential regions.

All households in the high potential regions and marginal regions, except small households in the lowlands zone, post gains in farm profits, again indicating that their productivity gains from technology adoption are greater than the increases in labor costs associated with the technologies. Households in the Moist Transition zone have the greatest profit gains because of their large output effects. The aggregate profit level is also higher (4.7%) than when the technology diffusion is limited to either one of the regions. As in Table 15a to 15c, welfare in urban households remains unchanged relative to the baseline because maize prices remain unchanged.

The aggregate real income changes by about 2.2%, compared to 1.8% for the highland region scenario and 0.3% for the marginal region scenario. All households, except small farm households in Dry Midaltitude zone and large farm households in the Moist Midaltitude, obtain increases in real income, with farm households in the Moist Transition zone getting the highest gains driven by huge farm profits that are, in turn, influenced by large output effects.

Table 15e assumes no technology change takes place in either the marginal or high potential region or both, but instead maize prices are exogenously increased by 20%, either by the government or effects of the world market. The price increase considerably

Table 15e. Fixed Price Model Results: No Technological Change, Maize Price Increase by 20%[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	3.88	7.88	5.98	6.64	7.40	6.36		6.84
Farm profits[2]								
▪ Small farms	**0.14**	**2.66**	**22.53**	**10.57**	**10.54**	**5.08**		**6.99**
▪ Returns to Land	-0.47	3.21	13.21	5.73	8.78	7.75		5.15
▪ Large farms	**10.71**	**2.73**	**26.54**	**3.26**	**9.66**	**3.28**		
▪ Returns to Land	8.69	3.09	13.90	0.31	9.24	4.16		
Real Income per capita								
▪ Small farms	2.42	13.03	8.80	12.77	13.21	18.30		10.44
▪ Large farms	2.29	14.72	24.00	0.24	24.57	20.77		
▪ Urban households							-2.10	
Price Index								
▪ Small farms	5.80	3.14	4.82	2.34	2.24	2.56		
▪ Large farms	9.44	0.52	3.94	9.96	3.30	1.90		
▪ Urban households							2.10	
Real Agricultural Wage								-0.99
General Price Index								2.94
Imports								-54.86

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to the baseline scenario (Table 15a).

[2] Bold figures represent combined returns to land and family labor.

boosts farm profits in all households, except among small farm households in the Lowlands zone for which maize profits is a small share of overall farm profits, resulting in an aggregate profits level that is higher than any of the preceding simulations. However, the weighted national maize production is much lower (6.8%), since there are no gains in maize productivity, than when there is technological change in the high potential regions (15%) or in both the marginal and high potential regions (19%).

Real incomes improve for all rural households, especially in the high potential regions, with the aggregate income increasing substantially by about 10% relative to the baseline scenario. However, urban household suffer loss in welfare from the price increases, which is different from previous simulations (Tables 15a-15d), which had no change in maize prices. The real agricultural wages are depressed by about 1%, partly due to lack of technological-induced labor demand increases, and overall maize import demand declines by about 55%, relative to the baseline.

When the maize price increase occurs in conjunction with technological diffusion in both marginal and high potential regions (Table 15f), the magnitude of increase in the weighted national maize production is greatest (25.8%) among all the previous simulations, relative to the baseline scenario. This huge increase in national maizr production causes maize import demand to decrease by 119% compared to the baseline case, indicating strong synergistic production effects between maize price increase and technological change. As in Table 15e, farm profits and income increase substantially, apart from a decline of the former in small households in the Lowlands zone and urban

Table 15f. Fixed Price Model Results: Technological Change in All Regions, Maize Price Increase by 20%[1] (% Change)

Parameter	Marginal Potential Zones			High Potential Zones			Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	10.83	20.43	19.85	34.35	36.40	14.46		25.82
Farm profits[2]								
▪ Small farms	**-0.96**	**4.76**	**18.57**	**13.42**	**20.79**	**9.71**		**9.73**
▪ Returns to Land	-1.98	-0.51	12.71	8.54	18.32	8.68		
▪ Large farms	**9.69**	**4.55**	**18.79**	**2.49**	**20.63**	**5.12**		7.30
▪ Returns to Land	6.35	1.09	10.84	-0.54	20.03	4.78		
Real Income per capita								
▪ Small farms	3.12	12.50	11.39	16.14	19.48	19.84		12.58
▪ Large farms	2.42	15.17	22.14	1.34	34.91	21.44		
▪ Urban households							-2.10	
Price Index								
▪ Small farms	5.80	3.14	4.82	2.34	2.24	2.56		
▪ Large farms	9.44	0.52	3.94	9.96	3.30	1.90		
▪ Urban households							2.10	
Real Agricultural Wage								7.78
General Price Index								2.94
Imports								-119.30

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to the baseline scenario (Table 15a).

[2] Bold figures represent combined returns to land and family labor.

households, resulting in a 9.7% increase in aggregate farm profits and a 12.6% increase in aggregate incomes, relative to the baseline scenario. Households in high potential regions gain but urban households are hurt by the maize price increases.

In summary, the simulations in the fixed-price model suggest a few things. First, large output effects and subsequent maize import declines accompany diffusion of maize technologies in high potential regions, with or without price changes. In contrast, wages are affected most when technological change occurs in marginal regions rather than in high potential regions, because of greater labor intensity and labor demand associated with adoption of maize technologies targeted to marginal regions. This is closely related to the fact that these technologies derive their yields gains mostly from labor-intensive agronomic recommendations compared to technologies for high potential regions (Table 13).

Second, the magnitude of the farm profits depend on whether a household is an adopter or non-adopter and on how labor intensive their maize farming and how large their wage effect is. Therefore, farm profits for technology adopters vary depending on the relative size of their output effects and the increase in production costs associated with adopting the new technologies. For non-adopters, farm profits decline as production costs increase without corresponding gains in maize productivity.

Third, impacts on real income vary depending on changes in labor wages and farm profits and the relative importance of these in the total household income. Labor from sale of agricultural labor is a significant source of income among small farmers in all regions, and more so in marginal regions (Table 12). The largest income effects accompanying technological change occur in the Moist Transition zone because of large output effects (Table 13). In general, positive income effects occur for almost all households when technology diffusion occurs in the high potential region but the effects are more mixed when technology diffusion occurs only in marginal regions.

Lastly, raising the price of maize exogenously without technological change increases farm profits and real incomes much more than when only technology change takes place in either one or both of the regions. However, this has less impact on maize production and maize import demand compared to when there is a technological change, and urban households suffer from the maize price increase. Seemingly, raising maize prices and, at the same time, encouraging diffusion of maize technologies complement each other: increases in national maize production, increases in real incomes, as well as decline in maize importation, are greatest in this scenario than all the other simulations under the fixed-price model. However, such increases in maize prices have to be generated from somewhere, presumably through increases in tax, so that the income gains attributed to increasing prices amount to an income transfer.

4.1.2 Flexible-Price Model Simulations

Tables 16a-f present simulation results of impacts of technological change in a flexible-price model in which maize prices are determined endogenously by maize demand and supply, similar to a closed-market economy, and maize imports or government's buffer stocks are used exogenously to bridge the gap between domestic production and consumption demand. One big difference between this model and the previous one (fixed-price model) is that here maize prices will respond to changes in quantity produced, thereby declining when diffusion of maize technologies results in increases in production. The baseline scenario (Table 16a), like in the fixed-price model, assumes no technological change in any of the regions but there is growth in exogenous income by 2.3% and growth in population by 3.1% per year for the 15-year period under consideration.

The baseline results predict that without technological change, and with population growth outstripping growth in non-exogenous income, there will be declines in real per capita income for all households (including urban households) and large (58%) increases in maize prices as excess labor supply depresses real agricultural wages by 63%. Although individual and aggregate farm profits are positive, especially due to cheap agricultural labor, household and aggregate real incomes decline significantly, the latter by as much as 41%.

Table 16a. Flexible Price Model Results: Baseline Scenario[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	16.13	26.69	23.84	26.08	29.85	26.32		27.54
Farm profits[2]								
▪ Small farms	**1.75**	**17.18**	**47.59**	**17.08**	**38.00**	**35.96**		**23.31**
▪ Returns to Land	5.74	30.48	67.40	30.09	44.24	39.52		30.89
▪ Large farms	**31.15**	**17.35**	**49.95**	**-1.29**	**40.04**	**24.14**		
▪ Returns to Land	44.22	26.12	76.82	6.62	41.54	25.31		
Real Income per capita								
▪ Small farms	-61.36	-52.09	-39.52	-58.60	-35.18	-45.55		-41.20
▪ Large farms	-56.96	-44.00	-4.96	-96.85	-32.90	-53.22		
▪ Urban households							-36.27	
Price Index								
▪ Small farms	19.67	10.65	16.35	7.94	7.60	8.68		
▪ Large farms	32.02	1.76	13.36	33.78	11.19	6.44		
▪ Urban households							7.12	
Real Agricultural Wage								-62.51
General Price Index								9.97
Real Maize Price								57.87

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes in which no technological change takes place and growth in population and exogenous income follow recent patterns.

[2] Bold figures represent combined returns to land and family labor.

Table 16b represents the scenario when technology diffusion occurs only in the marginal regions. Relative to the baseline, real agricultural wages rise by 7%, due to technological-induced labor demand in marginal regions, and maize prices fall by 3.6%. The change in the weighted national maize production is lower (2.7%) than the counterpart scenario in the fixed-price model (4.1%). Farm profits increase for adopters in marginal regions, except in the Lowlands zone where, output effects fail to compensate for increasing labor costs, and there is decline in farm profits for all non-adopters in the high potential regions. Real per capita income gains are experienced only by 5 out of the 8 households in marginal regions while the rest of the rural households suffer decline in real incomes, mostly as a result of increasing labor costs and the maize price decline associated with increased maize production. Urban households gain unambiguously from the price decline. Overall, the aggregate farm profits increase by only 0.3% relative to the baseline, while the aggregate real income increase by only 0.2%.

When technology diffusion occurs only in the high potential regions (Table 16c), the weighted national maize production increases by about 10%, depressing maize prices by 11.6%, both relative to the baseline scenario. The real agricultural wage increases by 2.7%, which is (like in the fixed-price model) smaller than the wage effect when technology diffusion occurs only in the marginal regions. All non-adopting households in marginal regions experience loss in farm profits, save for small farmers in the Lowlands zone and large farmers in the Dry Transition zone – whose proportion of farm profits from maize are least. What is different from the fixed-price model is that only adopters in the high potential regions post gains in farm profits, specifically large and small

Table 16b. Flexible Price Model Results: Technological Change in Marginal Regions[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	6.23	10.98	12.72	26.42	-2.11	-1.89		2.66
Farm profits[2]								
▪ Small farms	**-0.21**	**1.51**	**2.82**	**7.69**	**-1.25**	**-2.63**		**0.25**
▪ Returns to Land	-1.25	-4.04	-2.61	2.44	-3.36	-2.99		-2.30
▪ Large farms	**-0.37**	**1.24**	**2.28**	**3.07**	**-2.49**	**-1.87**		
▪ Returns to Land	-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		0.18
▪ Large farms	1.32	-0.18	-2.87	3.28	-2.12	-1.41		
▪ 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

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to the baseline scenario (Table 16a).
[2] Bold figures represent combined returns to land and family labor.

Table 16c. Flexible Price Model Results: Technological Change in Highland Regions[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	-2.74	-5.46	-4.19	-4.63	24.51	4.32		10.22
Farm profits[2]								
▪ Small farms	**0.40**	**-2.62**	**-7.65**	**-2.53**	**5.13**	**-2.91**		**-0.73**
▪ Returns to Land	-0.10	-3.38	-9.90	-3.28	4.33	-3.81		-1.47
▪ Large farms	**-4.91**	**-2.63**	**-7.58**	**1.09**	**5.16**	**-1.65**		
▪ Returns to Land	-6.55	-3.13	-1.64	0.64	4.96	-1.94		
Real Income per capita								
▪ Small farms	4.20	0.13	-0.19	-0.05	3.99	-0.99		1.31
▪ 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

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to the baseline scenario (Table 16a).

[2] Bold figures represent combined returns to land and family labor.

households in the Moist Transition zone with sufficiently large output effects that compensate for both the increases in labor costs and decreases in maize prices. All households in the Highlands zone suffer loss of farm profits as well, since their output effects are not large enough to counter the negative labor costs and price decline.

Similarly, real per capita income gains are highest for households in the Moist Transition zone whereas those in the Highlands zone suffer loss of welfare for reasons discussed above. In addition, half of the households in marginal areas gain in real per capita incomes. Urban consumers gain because of the larger price decline compared to when the technology diffusion occurs only in marginal regions. Households with large maize expenditure shares, such as large farmers in the Lowlands and Dry Transition zones, also gain from the price decline as well. Overall, the aggregate farm profits decline by about 0.7% while real aggregate incomes increase by 1.3%.

Table 16d displays results from the simulation when technology diffusion occurs in both marginal and high potential regions. The impacts on farm profits are almost similar to those in Table 16c, except that now small households in the Dry Transition zone join those who experience profit gains and also the gains are relatively smaller as a result of higher wages (9.7%) compared to 2.7% when technological change takes place only in the highland regions. Similarly, only 5 of the 8 households in marginal regions and the households in the Moist Transition zone experience gains in real per capita income. The rest, including households in the Highlands zone, suffer welfare loss. Urban households gain more here than when the technology diffusion occurs in either on the regions.

Table 16d. Flexible Price Model Results: Technological Change in All Regions[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	3.49	5.53	8.54	21.79	22.40	2.43		12.89
Farm profits[2]								
▪ Small farms	**0.19**	**-1.11**	**-4.70**	**5.15**	**3.91**	**-5.27**		**-0.42**
▪ Returns to Land	-1.35	-7.42	-12.51	-0.84	0.96	-6.80		-3.50
▪ Large farms	**-5.28**	**-1.39**	**-5.13**	**4.16**	**2.67**	**-3.43**		
▪ Returns to Land	-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		1.48
▪ 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

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to the baseline scenario (Table 16a).

[2] Bold figures represent combined returns to land and family labor.

Overall, maize production increases by 12.9%, which cause a 15% decrease in maize prices, while aggregate farm profits decline by 0.4% and real income increases by 1.5%.

Table 16e represents the scenario when there is no technological change but the baseline level of imports is doubled from the current national maize import demand of 22% to 44%. Relative to the baseline scenario, the national maize production declines by 12% and domestic maize prices decline by 30%, indicating a crowding out of domestic production by imports, a situation commonly observed whenever relatively large maize imports flood the domestic market. All households, except small farm households in the Lowlands zone and large farm households in the Dry Transition zone, experience losses in farm profits, mainly because of the huge maize price declines unaccompanied by any productivity gains.

The decline in farm profits does not spare even households in the Moist Transition zone, which show resilience when technology diffusion occurs in either or both the regions without change in maize imports. In fact, the negative trends are observed for real per capita incomes for all the households in the high potential regions and 4 out of the 8 households in the marginal regions. In general, the effects are good for net consumers and bad for net producers. Overall, real agricultural wages increase by 1.8% while aggregate farm profits and aggregate incomes decline by 8% and 2.3%, respectively.

When doubling of maize imports occurs concurrently with technology diffusion in both marginal and high potential regions (Table 16f), the decline in maize production is only

Table 16e. Flexible Price Model Results: No Technological Change, Doubled Imports[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	-6.90	-14.00	-10.63	-11.80	-13.15	-11.30		-12.15
Farm profits[2]								
▪ Small farms	**1.82**	**-6.41**	**-11.44**	**-0.83**	**-14.62**	**-17.29**		**-8.05**
▪ Returns to Land	0.30	-7.38	-23.96	-7.10	-17.08	-15.41		-10.52
▪ Large farms	**-5.28**	**-6.41**	**-8.28**	**6.53**	**-17.01**	**-9.71**		
▪ Returns to Land	-15.90	-7.06	-25.27	2.72	-17.61	-9.09		
Real Income per capita								
▪ Small farms	9.40	0.13	-1.38	-0.37	-5.38	-7.17		-2.31
▪ Large farms	8.70	-4.25	-13.88	19.52	-10.93	-5.17		
▪ Urban households							3.73	
Price Index								
▪ Small farms	-14.60	-5.58	-8.56	-4.16	-3.98	-4.55		
▪ Large farms	-31.18	-0.92	-7.00	-17.69	-5.86	-3.37		
▪ Urban households							-3.73	
Real Agricultural Wage								1.76
General Price Index								-5.22
Real Maize Price								-30.31

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to the baseline scenario (Table 16a).

[2] Bold figures represent combined returns to land and family labor.

Table 16f. Flexible Price Model Results: Technological Change in All Regions, Doubled Imports[1] (% Change)

Parameter	Marginal Potential Zones				High Potential Zones		Urban	National
	Lowlands	Dry Midaltitude	Moist Midaltitude	Dry Transition	Moist Transition	Highlands		
Maize production	-3.41	-8.48	-2.09	9.99	9.25	-8.88		-0.73
Farm profits[2]								
▪ Small farms	**1.03**	**-7.51**	**-26.48**	**-0.99**	**-12.72**	**-20.17**		**-10.28**
▪ Returns to Land	-1.06	-14.80	-36.47	-7.94	-16.11	-22.21		-14.02
▪ Large farms	**-19.33**	**-7.80**	**-27.45**	**7.46**	**-14.83**	**-12.35**		
▪ Returns to Land	-26.22	-12.60	-41.00	3.23	-15.65	-13.03		
Real Income per capita								
▪ Small farms	16.35	-0.34	0.51	2.81	-1.81	-9.22		-1.26
▪ Large farms	15.83	-5.94	-22.71	30.41	-6.07	-7.10		
▪ Urban households							5.60	
Price Index								
▪ Small farms	-15.47	-8.38	-12.86	-6.24	-5.97	-6.83		
▪ Large farms	-25.18	-1.39	-10.51	-26.57	-8.80	-5.07		
▪ Urban households							-5.60	
Real Agricultural Wage								11.42
General Price Index								-7.84
Real Maize Price								-45.51

[1] Assumes no change in maize prices, and thus no change in household specific price indices. All values denote percentage changes relative to the baseline scenario (Table 16a).

[2] Bold figures represent combined returns to land and family labor.

0.7% compared to 12% (without accompanying technological change). However, maize prices decline by 46% and real agricultural wages increase by 11%, compared to 30% and 2%, respectively, when there is no technological change. These changes in maize price and wages lead to losses in farm profits for most houses, except small farms in the Lowlands zone and large farms in the Dry Transition zone. Also, all households in high potential regions and 3 out of 8 of households in the marginal regions suffer losses in real income. Households that experience gains in real income are those with larger shares of their income from labor earnings and also those with a high maize expenditure share. Overall, the aggregate real income declines by 1.3% while aggregate farm profits decline by 10.3%.

In summary, a few points can be deduced from these simulations. First, because output effects from technology adoption are accompanied by a maize price decline in this model, impacts on farm profits and real income tend to be lower in these flexible-price models than in the fixed-price models. Since these output effects are larger when the technology is adopted in high potential regions that when adoption is confined to marginal regions, the price declines are greater in the former than in the latter model scenarios.

Second, maize price declines accompanying output effects in the flexible-price model represent a positive effect especially for net consumers with large maize expenditure shares such as large farmers in the Lowlands and Dry Transition zones. Whether these positive price effects and earnings from sale of agricultural labor are sufficient to outweigh declines in farm productivity and increasing labor costs as agricultural wage increases is what determines whether households experience gains or loses in real income, relative to the baseline. Lastly, urban consumers gain unambiguously because of the price declines, a significant difference compared to unchanged welfare under the fixed-price models.

4.2 Aggregate Income and Farm Profit

Table 17 presents a synthesis of aggregate income and farm profit effects of the various technology scenarios discussed in the previous two sections.[13] The aggregate income effects are computed as sums of real per capita income changes for all households in a specific simulated scenario, weighted by population shares, and represent the average percentage change in real income per capita for that scenario. Similarly, the aggregate farm profits effects are computed as sums of farm profit changes for all households in a specific simulated scenario, weighted by population shares, and represent the average percentage change in farm profits for that scenario.

The results presented in Table 17 indicate that, irrespective of the technology change scenario, aggregate income effects are greater in the fixed-price model (when maize prices are exogenously determined) than in the flexible-price model (when maize prices are endogenously determined). In addition, within each of the models, the aggregate income effects are greater when technological change occurs in high potential regions than when it occurs in marginal regions. However, the greatest income effects are

[13] The individual results are assembled from Tables 15a-f and Tables 16a-f.

Table 17: Aggregate Farm Profit and Income Effects, and Gini Coefficient By Technology Change Scenarios

Model Closure Condition	Technology Change Scenario	Aggregate Farm Profit Change (%)[1]	Aggregate Income Change (%)[2]	Gini-Coefficient
With p=0%:				
Fixed Price	Baseline, No Tech Change	4.41	-37.40	0.262
Fixed Price	Marginal Region Only	1.49	0.30	0.257
Fixed Price	High Potential Region Only	2.89	1.84	0.260
Fixed Price	All Regions	4.69	2.17	0.257
With p=20%:				
Fixed Price	Baseline, No Tech Change	6.99	10.44	0.236
Fixed Price	All Regions	9.73	12.58	0.235
With G=0%:				
Flexible Price	Baseline, No Tech Change	23.31	-41.20	0.259
Flexible Price	Marginal Region Only	0.25	0.18	0.254
Flexible Price	High Potential Region Only	-0.73	1.31	0.261
Flexible Price	All Regions	-0.42	1.48	0.259
With G=100%:				
Flexible Price	Baseline, No Tech Change	-8.05	-2.31	0.265
Flexible Price	All Regions	-10.28	-1.26	0.266

[1] Computed as Sum of all households' farm profit changes weighted by population shares.

[2] Computed as Sum of all households' real income changes weighted by population shares.

achieved when the technology diffusion occurs in both marginal and high potential regions.

Exogenously raising maize prices by 20% in the fixed-price model increases, substantially, the aggregate income effects, relative to the baseline, compared to without-price-change scenarios. The changes are larger when technology diffusion occurs in both regions compared to when it occurs in either of the regions. In contrast, the flexible-price model exhibits lower aggregate income effects, which become worsened by doubling of maize imports.

As in the case of aggregate incomes, the aggregate farm profit effects are higher for the fixed-price model than for the flexible-price model for every corresponding scenario. The effects are also greater when technology diffusion occurs in the high potential regions than in marginal regions in the fixed-price model, because of larger output effects associated with technology adoption in the former, and the effects are larger when the technology diffusion occurs in both marginal and high potential regions than when it is confined to either one of the regions.

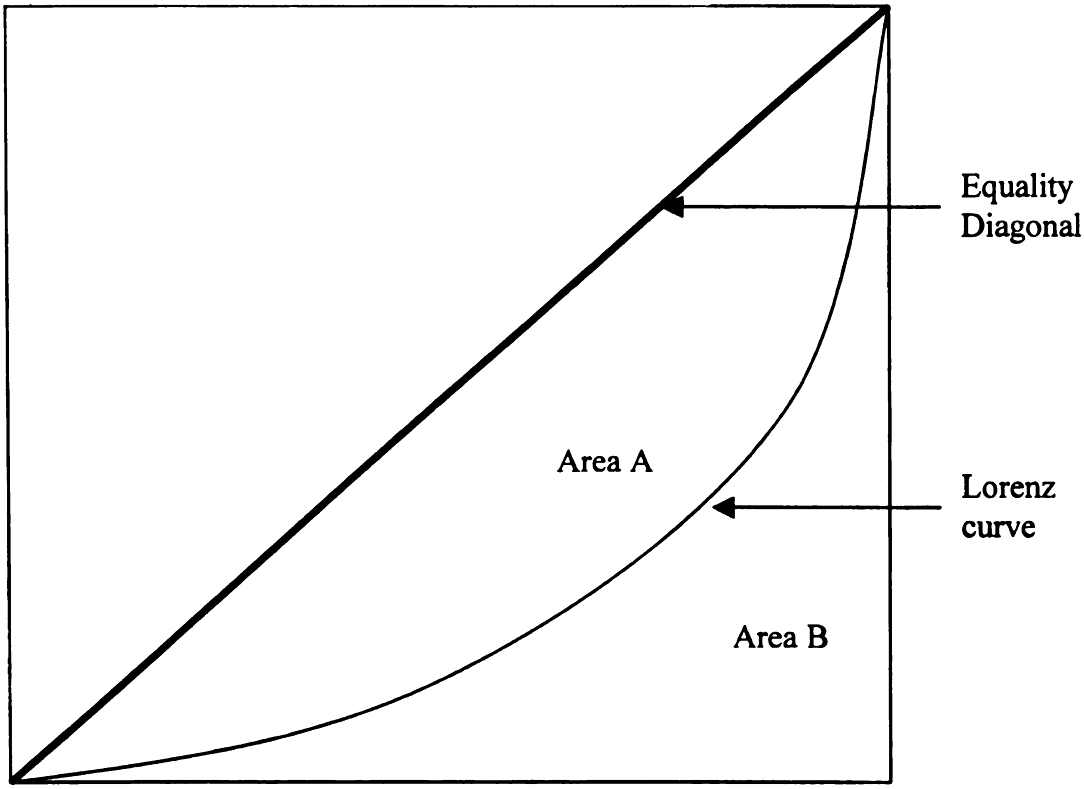
But this is not true for the flexible-price models, where aggregate farm profits are greater when the technology is confined to marginal regions than when it is confined to the high potential regions. Whereas raising maize prices exogenously by 20% in the fixed-price model results in higher aggregate farm profits, increasing maize imports in the flexible-price model results in much lower aggregate farm profits, relative to the baseline.

4.3 Income Distribution Effects

Equitable distribution of income in Kenya has been expressed as a desirable policy goal for Kenya's agricultural and economic development (Kenya, 1998). Gini coefficients were computed to explore the impact of maize technology diffusion on income distribution as simulated by the fixed-price and flexible-price models. A Gini coefficient is based on estimation of a cumulative frequency curve, the Lorenz curve, which compares the distribution of a specific variable with uniform distribution that represents equality (Figure 12). The greater the deviation of the Lorenz curve from the diagonal, the greater is the inequality. The coefficient can also be calculated as the ratio of the area between the Lorenz curve and the diagonal line, and the entire area below the diagonal line.

The results of the Gini computations are shown in the last column of Table 17. The baseline Gini coefficient is 0.262 for the fixed-price model and 0.259 for the flexible-price model. In general, although diffusion of maize technologies in high potential regions have greater aggregate impacts on farm profits and real income, the Gini computations reveal that their income distribution effects are inferior to diffusion of technologies in marginal potential regions. In the fixed-price model simulations, the computed Gini coefficients indicate that income distribution improves under both the marginal region and the high potential region scenarios, compared to the baseline, but that income distribution is more even under the former. In the flexible-price models, the computed Gini coefficient for the marginal region simulation is lower than for the

Figure 12: Calculation of the Gini Coefficient*



* The Gini Coefficient is calculated as: Area A/(Area A+B)

baseline, signifying better income distribution in the former, whereas the Gini coefficient for the high potential region is greater than that of the baseline, indicating poorer distribution effects in the highlands compared to the baseline.

4.4 Sensitivity Analysis

In order to test how sensitive the simulation results were to changes in various elasticities and shares, a sensitivity analysis was done. First, elasticities of maize output and input supply and demand were systematically doubled, one by one, and simulated changes in endogenous variables noted. Likewise, shares of input demand and supply, profit, income and expenditure were also systematically doubled, except for income shares, which were increased by 30%, and changes in endogenous variables noted.[14] Tables 18a and 18b present the results of these analyses for the fixed-model and flexible model, respectively.

In general, the two models are fairly insensitive to most of the changes in elasticities and shares. However, in the fixed-price model, a doubling of the labor demand and supply elasticities yield changes in the wage rates as large as 37% for the labor demand and 31% for the labor supply. Apart from a 19% decline in aggregate farm profits with a doubling of labor demand elasticity, none of the other endogenous variables changed by more than 3%. When the labor supply elasticity was doubled, none of the other endogenous variables changed by more than 6%. Similarly, the maize import demand was sensitive to

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[14] Doubling income shares on large farms in the highlands zones would exceed 100%.

Table 18a: Sensitivity Analysis of Selected Elasticities and Shares for the Fixed-Price Model

Parameter (% Change)	Maize production	Aggregate farm profits	Aggregate income	Wage rate	Import demand
	% Change				
Fixed Price -Elasticities:					
Maize supply (+100%)[1]	-15%	-17%	-6%	0%	-11%
Labor demand (+100%)	-1%	-19%	-3%	37%	-0.5%
Labor supply (+100%)	-0.7%	-6%	-1.3%	31%	-0.4%
Maize demand (+100%)	0%	0%	0%	0%	-32%
Fertilizer demand (+100%)	0%	0%	-0.03%	0%	0%
Income demand (+100%)	0%	0%	-0.03%	0%	10%
Fixed Price -Shares:					
Profit (+100%)	0%	-19%	-31.6%	0%	6.7%
Expenditure (+100%)	0.43%	3.6%	21%	12.5%	-3.8%
Income (+30%)[2]	0%	0%	-33%	0%	3.1%

[1] Refers to own-price elasticity.
[2] 30% is used because large farms maize income share would exceed 100% if doubled.

Table 18b: Sensitivity Analysis of Selected Elasticities and Shares for the Flexible-Price Model

Parameter (% Change)	Maize production	Aggregate farm profits	Aggregate income	Wage rate	Real maize price
	% Change				
Flexible Price -Elasticities:					
Maize supply (+100%)[1]	-7.2%	-6%	-13.5%	1.3%	24%
Labor demand (+100%)	-9.6%	3.7%	11%	10.4%	-0.1%
Labor supply (+100%)	-29%	3.6%	8%	34%	-0.4%
Maize demand (+100%)	-18%	7%	6.9%	8%	12.5%
Fertilizer demand (+100%)	0%	0%	-0.03%	0%	0%
Income demand (+100%)	-9%	-2%	-16%	5.3%	23%
Flexible Price –Shares:					
Profit (+100%)	-17%	-21%	-9.6%	4.7%	20.4%
Expenditure (+100%)	-7%	4.8%	14%	-10%	-26%
Income (+30%)[2]	-9%	-1.9%	12.3%	5.4%	23%

[1] Refers to own-price elasticity.

[2] **30% is used because large farms maize income share would exceed 100% if doubled.**

the output demand elasticity. Finally, aggregate income changes were somewhat sensitive to profit and income shares.

In the flexible-price model, real maize price changes are sensitive to both maize supply elasticity and the expenditure share, exhibiting an increase of over 20% with a doubling of the former and a decrease of 26% with a doubling of the latter. The maize supply elasticity used in the simulations was one of the elasticities that were drawn from a study that is specific to Kenya and was adapted from Munyi (2000), which is base on similar time-series data. The expenditure shares were estimated from Kenya (1994), whose sampling frame is the foundation of this study. Whereas the labor demand and supply elasticities were not computed from the Kenyan maize case, I am fairly confident of the parameters computed in this study and those used from Munyi (2000). Since getting appropriate elasticities proved to be a great challenge for this study, it is comforting that the choices made were not overly distorting.

CHAPTER 5

5.1 Conclusions and Implications for Research and Policy

The objectives of this study were threefold. First, to determine the status of production, consumption and technology adoption for maize, the most important food crop in Kenya. Second, to evaluate the impact of "on the shelf" technologies on farm profits and income distribution for different households and regions in Kenya. The third objective was to enable maize researchers and managers to use this information to make R&D investment decisions. In this regard, Chapter 2 presented detailed findings on the first objective while Chapter 4 provided detailed simulations on the second objective. This chapter synthesizes these findings and discusses the implications for future research and policy. The study used a multi-market model, rather than other models such as the economic surplus model, in order to explore the effects of regionally differentiated technological change at a household level and accommodate differences between households, some of which are joint consumers and producers of maize, and sometimes also providers of farm labor.

5.1.1 From Descriptive Analysis

Chapter 2 presented an update of the status of maize production, consumption and technology use in Kenya, and differentiated these by small and large farms in different production regions, classified as marginal and high potential regions. Traditionally, agricultural policies in Kenya have been made using these farm size and regional classifications. This study used agro-climatic regions based on geo-referenced data and information that allow tailored recommendations for research managers and policy makers.

The findings from the descriptive analysis in Chapter 2 confirmed maize is the most important food staple in Kenya, as it accounts for large production and consumption shares for the bulk of the population. Therefore, any technological, institutional and policy changes affecting maize production and prices are bound to have significant effects on the incomes and welfare of many people, both producers and consumers. The high potential regions are the dominant maize production zones and together accounted for more than two-thirds of the total output and nearly half of the total area under maize in 1996-98. These regions have about 1.9 million agricultural households and almost half of Kenya's population.

Maize technologies used by farmers differed by regions, farm households and seasons. Therefore, it is important that research recommendations be differentiated accordingly to maximize the technologies' potential productivity. The different conditions, locations and seasons under which maize is grown in the country present a great challenge to research resource allocation, because they require tailored research, recommendations and, sometimes, technology transfer. However, the effort to do this has been greatly enhanced by the new regional classification, as used in this study.

Considerable human, physical and fiscal resources have been spent on maize research and extension in the past decade or so, but there seem to be little change in the level and type of technologies used, and the level of productivity achieved by maize farmers. For instance, between 1992 and 1998, there was a 5-6% decrease in the use of hybrid seed by small and large farmers, and a 9% and 16% increase in the use of basal fertilizer in small and large farms, respectively. These changes, though slight, took place after restructuring of the Kenya's maize marketing.

Most farmers prefer maize variety (H614, first developed in 1976 and renewed in 1986) and unimproved "local" maize varieties. This issue raises three questions: (1) where are the new hybrids and open-pollinated varieties that were released after H614; (2) why are these technologies "on-the-shelf"; (3) why were fewer varieties released from the research institution in the 1990s compared to the 1960s, 1970s and 1980s? These questions are beyond the scope of this study but should be considered by research managers and policy makers.

It is worth noting that the increase in the number of farmers using fertilizer on maize in 1998 was accompanied by a decline in the amount of fertilizer used at planting, with most farmers attributing the change to higher input costs and lower post-liberalization market incentives. Combining this with the fact that there seems to be declining soil fertility and little change in varietal choices for farmers, it is not surprising that maize yields have stagnated over the past decade. In fact, the average yield for small farmers was 1.38 t/Ha in 1992 and 1.59 t/Ha in 1998, and for large farmers these were 2.62 t/Ha and 2.73 t/Ha, respectively, signifying almost no change in productivity over the 1992-98 period. In addition, the gap between farmers' and research yields at 50-70% is large, and points to an unexploited potential. Meanwhile, the outcome of stagnating maize productivity in the face of a rapid population growth is increases the reliance on imports to meet future maize demands, which is hard for an economy that is increasingly lacking foreign exchange earnings.

Two important trends from the data in Chapter 2 are worth highlighting because they raise serious policy concerns for the future of maize production in Kenya. First, there was a large decline (45%) in the number of farmers that had access to extension services in 1998 compared to 1992. According to Karanja (1996), the increase in maize production in the late 1960s and 1970s is attributed to adoption of improved maize seeds and complementary technologies made possible by a dynamic synergy between the research, extension and the seed multiplication and distribution programs.[15] However, a recent expiration of the Training and Visit (T&V) extension program of the World Bank and lack of alternative funding sources are blamed for the decline in extension access, and underscore the need for sustainable funding of such essential services.

The second trend of concern is the continued lack of access to farm credit, especially among small farmers, which has been identified as a significant constraint to agricultural development in Kenya (KARI, 1993; Karanja, 1996). In the past, only about 10% of

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[15] Other studies, such as Karanja (1990) and Hassan, Karanja and Mulamula (1998), have indicated the importance of agricultural extension in the expansion and growth of Kenya's maize production.

maize farmers have been able to access low-interest credit offered by the now collapsed government-controlled Agricultural Finance Corporation, mainly as seasonal crop loans (Hassan, Karanja and Mulamula, 1998). So far, none of the commercial banks lend to smallholder maize farmers, and this is bound to limit the level of agricultural intensification needed to raise agricultural productivity.

The effects of maize market liberalization in Kenya are not clear; the government backtracked several times on their commitment to fully liberalize maize markets, such that intended policy and structural changes took long to occur (Jayne and Kodhek, 1997; World Bank, 2000). However, the data also reveals that, with maize liberalization, there was an increase in the number of farmers who are net sellers of maize. This is may be partly because there was an increase in the number of maize traders, who operated bicycles and small pick-up trucks, and managed to penetrate remote areas, compared to the monopoly marketing board that opened maize-buying depots in major maize-growing regions during the previous, government-controlled maize marketing era. In general, farmers had no preference for either the current or the former marketing system; the current marketing system offers prompt payment for produce purchases but only controls small volumes of sales at any one time, and tend to bid for low prices. In contrast, the former marketing boards offered higher producer prices, bought large volumes but delayed payments (Nyoro, 1992).

Two characteristics related to the farmers raise concern - age and gender. The average age of maize farmers is high (44 years) and almost equivalent to Kenya's average life expectancy of 47 years, at a time that there is a high level of unemployment for young people in rural areas. This is a tough policy issue to resolve since it involves traditional land bequeathing systems and lack of land ownership rights for women and young men. Controlling for experience, age is inversely related to technology adoption, and has implications on farm productivity (Feder and Umali, 1993; Hassan and Karanja, 1997). The second issue is gender. In 1998, women farmers comprised one-half of the small farmers and less than one-quarter of the large farmers that were interviewed, reflecting a gender bias on land allocation.

In summary, there are numerous technological, institutional and policy issues that require urgent attention if maize production is to be increased to meet growing consumption demand. The past decade has shown little progress in form of new technologies, increased adoption of these technologies and productivity increases. Therefore, there has been stagnation in maize yields, which when coupled with limited arable land for maize area expansion, is cause for diminished productivity and increased reliance on maize imports to meet the growing maize consumption demand. However, importing maize is often a difficult experience for Kenya for three reasons. First, the timing of importation has been a problem in the past conflicting with domestic production by depressing local prices at harvest.

Second, Kenya's economy is hard-pressed and will find it hard to finance large imports, Finally, the roads infrastructure has deteriorated significantly in recent years such that the cost of distribution of such maize will make it expensive to the detriment of consumer welfare. Therefore, a viable long-term strategy must include developing or adapting maize technologies (mostly agronomic and yield-loss reduction rather than breeding new high-yielding varieties) and developing supportive institutional capacity for extension, credit and infrastructure that lower the cost of production and increase productivity.

5.1.2 From Multi-Market Model Simulations

The decision by research managers and policy makers about where to invest scarce research resources becomes extremely difficult without information on how research products or technologies affect peoples' livelihoods. This study chose maize because it is the most popular food crop in Kenya, and also because it is the most researched, thus, it has numerous data useful for such elaborate simulations. This section summarizes the findings of the impacts of "on the shelf" maize technologies on income and profits for different farms household in different regions, and also for urban consumers, under different maize market policy scenarios in Kenya. Basing the analysis on farm size and regional categories fits the way Kenya's agricultural development debate is currently framed.

Simulations in Chapter 4 show that in 15 years, in the absence of injection and adoption of new streams of maize technologies, maize import demand will increase by 165% over the current levels of imports if a fixed-price market regime is pursued and maize prices will increases by nearly 60% if a flexible-price maize policy regime is followed. In both cases, real agricultural wages will decrease by 60% as population growth leads to increases in labor supply, which in the absence of labor-demanding technological change, or emigration, puts a downward pressure on wages. Technological change, especially in the high potential regions, is associated with increased maize productivity and subsequent reduction in maize import burden, as well as increased farm profits and real income. More specifically, the net impact of new technologies on real household incomes depends on change in wages and profits engendered by adoption of those technologies and the relative importance of these two components in the household income.

Simulation results indicate that the positive effects of wage increases on farm labor income generally outweighed the negative profit effects in the overall distribution of benefits and losses. The impacts on labor earnings were particularly beneficial for small farmers, especially in marginal regions where the maize technology is more labor intensive. Therefore, wages are more profoundly affected in scenarios in which technology adoption occurs in the marginal regions. In contrast, diffusion of improved technologies in the high potential regions has a much stronger positive impact on national maize output than scenarios in which diffusion is confined to marginal regions, because of larger output effects in the former.

Typically, changes in the farm profits of different farm households in different locations depend on two factors: whether or not the household is a technology adopter and how labor intensive maize farming is for the particular households. Farm profits inevitably fall for non-adopters since 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 terms of the magnitude of simulated income effects of technology adoption, it is clear that the largest increases in profits are achieved in the high potential regions.

The results of the simulations suggest some general conclusions regarding the potential welfare effects of diffusion of maize technologies currently on the shelf in Kenya. First, maize technologies that have been developed for high potential regions will continue to have greater aggregate impact on maize production and will, thus, lead to greater reductions in import demand if prices are controlled or reduction in maize prices if maize prices are flexible. Second, diffusion of technologies in these regions is likely to have substantially greater positive impacts on aggregate real income and farm profit, with effects being greater for simulations in which technology diffusion occurs in the high potential regions, with or without diffusion in marginal regions. 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.

Simulations assuming exogenous maize prices increases of 20 percent in the case of fixed-price model or doubling of current levels of maize imports in the case of the flexible-price model, with or without technological change taking place, have larger effects on aggregate income and farm profits. The former generated large positive impacts on farm profits and real income, greater than that generated by technological change in either or both the production environments. This is because technological change are limited by relatively low net yield potential in most zones and the fact that technological change is accompanied by negative wage effects, especially in marginal regions where the technology is more labor-intensive.

However, increasing maize prices alone has minimal impact on reducing import demand and uncertain output effect. Indeed, the aggregate effects on income are maximized when the exogenous price rise is accompanied by technological change, indicating there is a synergy between both policy options. But it is important to note that there is a cost to achieving any of these options, including funds to boost maize prices and facilitate adoption of these technologies, and the money must come from somewhere, a discussion that is currently beyond this study.

On the other hand, an increase in maize imports in the flexible-price model diminishes aggregate farm profits and real income. The accompanying decline in maize prices, when output increases from adoption of technology in one or both the production regions or from more importation of maize, increases the welfare of urban households and other net-consuming households that benefit from food price declines. In contrast, net producers suffer loss from price declines if their output effects from technological change do not compensate them from price decline. This demonstrates that policy choices matter and may have great ramifications on who gains and who loses.

The analysis in this study also show that the diffusion of maize technologies in marginal regions has better income distribution outcomes although the aggregate output impacts on incomes are smaller than technologies targeted for high potential regions. As to which of these goals - increasing income levels or increasing equity - is more desirable policy choice is a matter that policy makers will have to decide, especially in lieu of the wider market liberalization policy debate, and important decisions on maize research and development resource allocations.

In conclusion, this study set out to simulate the impacts of technological change on farm profits and income both within and across different production environments. The overall results indicated that the effects are indeed different, both for different household types (including urban consumers) and different production regions. Prior knowledge of these effects before selection and implementation of any of the policy strategies is extremely important. It is wrong to assume that, as has been the case, raising producer prices will solve all the problems and make everyone better off, since it is evident that some households will gain and others lose. Also, it is important to note that there are other critical avenues of transmission of technological benefits and losses, rather than just commodity markets. The very design of appropriate technologies targeted for different regions must take that into consideration. This study shows that, beyond the commodity market effects, there were significant labor market effects, especially for small farmers. Such information and ex-ante knowledge of potential income distribution effects of technologies at the design phase can be a great asset to researchers and policy makers to achieve desirable equitable development objectives.

5.2 Study Limitations

Several limitations of the multi-market model used in this study are worth noting. First, the model is simplified to enhance the ability to interpret the results, which means that its capacity to capture "real world" effects is deliberately compromised. A two-input, two-output production system and a two-product consumption system were assumed to allow following through of the impacts of changes in production, consumption, price, etc. due to simulated external technological changes. However, failure to do these would yield results that are too complex and meaningless.

Second, data is always a major limitation in studies like this. Lack of data and time to get actual estimates of various elasticities made it necessary to "borrow" values from other studies. Although sensitivity analysis was done on these parameters to test the level of distortion introduced on the base output by using these values, it is always more certain when using actual data applicable to a specific region. Related to this, making meaningful income distribution assessments requires assembling information on the initial income distribution across the various households. This facilitates comparison with simulated posterior distributions. Meanwhile, the ability to geo-reference demographic, agro-climatic and socio-economic data allows for an integrated spatial analysis that is more realistic. Therefore, the use of GIS to collate needed data and information may be useful in enhancing the accuracy of such models.

Third, the model results underestimate the impacts of technological change since these are limited to effects of changes in farm profits, changes in labor demand hence real wages, and changes in maize prices. For instance, the model does not account for changes in rural incomes from multiplier effects of investing surplus agricultural income on rural non-agricultural activities, it does it include effects of non-agricultural income, which is considered exogenous, and also ignores changes in nominal urban wages from changes in food prices and rural-urban migration.

Fourth, this model represents snapshots of two static time periods, one before technological change and the other after the effects have occurred, rather similar to assuming instantaneous changes. Such a model, therefore, cannot capture interesting dynamic effects of market equilibration. However, the snapshots of "with" and "without" technological change provide important information on technology effects and policy implications.

Lastly, this modeling does not account for the cost of implementing the said technological and price changes, and therefore, cannot be used to estimate potential benefit-cost ratios of different technology and policy options that may be needed for a more comprehensive analysis of these scenarios to inform priority setting and definite resource allocation. But still, the current analysis makes important contribution to estimating the direction and scale of impact of different technologies on different households in different regions, and these can be readily updated as more information becomes available.

APPENDICES

APPENDIX A

1999 Farm-Level Survey Questionnaire

ACCEPTANCE TO PARTICIPATE/ RUHUSA YA KUHOJIWA:
Tunafanya utafiti kuhusu umuhimu wa teknolojia ya mahindi kwa kuongeza mazao na mapato kutokana na ukuzaji wa mahindi katika sehemu mbali mbali za Kenya. Tutashukuru kwa usaidizi wako wa habari kuhusu ukuzaji wa mahindi na jinsi wewe unavyojaribu kuongeza au kudumisha ukuzaji.

MAJIBU YAKO NI YA HIARI NAITAWEKWA SIRI KABISA. Baadaye yatajumulishwa na mengine mia tatu ili kutoa ripoti kuhusu teknolojia ya mahindi.

1. Location Identification (LOC): Complete this section last.

District:	**Village:**
Division:	**Cluster Code:** **Household No:**
Location:	**Date of Interview:**
Sub-Location:	**Name of interviewer:**

2. Farmer Identification:

a. Name of farmer:_________________________________ b. Sex: ( ) Male; ( ) Female

c. Age (Years):_______ d. Education: ( ) None; ( ) Primary; ( ) Secondary; ( ) Degree/Diploma

3. Farm Production System:

a. Total farm size (acres): Own_____; Rented_____; Shared_____

b. Total area under maize:

i. Variety ______________acres______ ( )pure; ( )intercropped with__________________

ii. Variety ______________acres______ ( )pure; ( )intercropped with__________________

iii. Variety ______________acres______ ( )pure; ( )intercropped with__________________

iv. Variety ______________acres______ ( )pure; ( )intercropped with__________________

c. Major enterprises besides maize (acres):

i. ______________________ acres_________( ) pure; ( )intercropped with_____________

ii ______________________ acres_________( ) pure; ( )intercropped with_____________

iii ______________________ acres_________( ) pure; ( )intercropped with_____________

iv ______________________ acres_________( ) pure; ( )intercropped with_____________

v ______________________ acres_________( ) pure; ( )intercropped with_____________

d. Major maize production season: ( ) 1st rains (Mar-Aug); ( ) 2nd rains (Oct-Feb); ( ) Both

e. List major constraints to maize production on your farm in the order of importance:

i. ____

ii. ____

iii ____

iv ____

v ____

4. Importance of Maize Production:

a. List the reasons why you grow maize (in order of importance):

i ____

ii ____

iii ____

iv____

b. Among the crops you grow, which one(s) is (are) the **major source of food** (in the order of importance)?

i ____________________	iv ____________________
ii ____________________	v ____________________
iii____________________	vi ____________________

Among the crops you grow, which one(s) is (are) the **major source of cash** (in the order of importance)?

i ____________________	iv ____________________
ii ____________________	v ____________________
iii____________________	vi ____________________

5.a. Maize Production Information by Major Plot:

Attribute	Long Rains 1998	Short Rains 1998
Area of major maize plot	________________(Acres)	______________(Acres)
Location	( )Home; ( )Away; If away, distance from home _____(km)	( )Home; ( )Away; If away, distance from home __(km)
Slope of field	( )0-25%; ( )25-50%; ( )50-75%; ( ) >75%	( )0-25%; ( )25-50%; ( )50-75%; ( ) >75%
Soil erosion problem?	( )yes; ( )no	( )yes; ( )no
Erosion control method?	( )none; Method__________	( )none; Method________
Land Tenure	( )own; ( )use right; ( )rent; ( )share; ( )other__________	( )own; ( )use right; ( )rent ( )share; ( )other________
Cropping system	( ) pure; ( ) intercrop; ( ) other	( ) pure; ( ) intercrop; ( ) other
If intercrop, with what?	main _____; minor________	main _____; minor_______

5.b. Maize Technology Characteristics & Availability

Attribute	**( ) Long Rains 1998; ( ) Short Rains 1998**
Name of Major Variety	______________; Acres______________
Seed rate on major plot	_____Kg/Plot or _____Kg/Acre
Source of Seed	( )buy; ( )own; other___________________
Reason for choosing major variety	( )drought tolerant; ( ) stores better; ( )sweeter; ( )yields higher; ( )stable yield; ( )better fodder; other______
If using non-Hybrid: Why not use hybrid	( )expensive; ( )not available; ( ) don't know how to use; ( ) need additional labor; ( )not aware of seed; ( )other_________
Seed available at right time:	( )always; ( )sometimes; ( )never
Seed available at local store:	( )always; ( )sometimes; ( )never
Appropriate seed available	( )always; ( )sometimes; ( )never
Use Basal fertilizer Basal Amount Topdress Fertilizer Topdress Amount Manure Manure Amount	( )none; ( )type______________ _______Kgs **or** (___Kg-Bags/plot) ( )none; ( )type______________ _______Kgs **or** (___Kg-Bags/plot) ( )yes; ( )no ______Kgs **or**______ units:_______
If not using fertilizer, why not?	( )expensive; ( )not available; ( )don=t know how to use; ( )other___________________
Is fertilizer available at the right time?	( )always; ( )sometimes; ( )never
Is fertilizer available at the local store	( )always; ( )sometimes; ( )never
Is the appropriate fertilizer available?	( )always; ( )sometimes; ( )never
Is manure available?	( )always; ( )sometimes; ( )never

5.c. Other Maize Farm Operations

Attribute	**( ) Long Rains 1998; ( ) Short Rains 1998**
Tillage method Tillage date	( )tractor; ( )oxen; ( )hoe; ( )oth Month_____Week: 1 2 3 4
Planting method Planting date Relation to Onset of Rain	( )tractor; ( )oxen; ( )hoe; ( )oth Month_____Week: 1 2 3 4 Before____At____After____
Number of weeding(s) Method of 1st weeding Date of 1st Weeding Method of 2nd weeding Date of 2nd Weeding	___________ ( )tractor; ( )oxen; ( )hoe; ( )chem Month___week: 1 2 3 4 ( )tractor; ( )oxen; ( )hoe; ( )chem Month___week: 1 2 3 4
Control field pest	( )no; ( )chem; ( )other________
Other chemical(s) used	( )none; name:________________
Amount of chemical used	______________units_______
Chemical availability	( )always; ( )sometimes; ( )never
Harvest green? How much?	( )no; ( )yes; ( )0-25%; ( )25-50%; ( )50-75%; ( )75-100%
Is there land to rent?	( )yes; ( )no
If not renting land, why?	( )expensive; ( )not available;

5.d. Alternative Crop:

i. After maize, what is the next most important crop you grew in 1998?_____________

ii. Would you vary the amount of land between maize and this crop? ( )yes; ( )no

iii. Would you vary your labor allocation between maize and this crop? ( )yes; ( )no

iv. Would you vary your fertilizer between maize and this crop? ( )yes; ( )no

v. Planting date for the alternate crop in 1998: Month______week: 1 2 3 4

vi. Harvesting date for the alternate crop in 1998: Month______week: 1 2 3 4

vii. Yield of alternate crop in 1998: ___________(units______/acre)

viii. Yield of alternate crop in a normal year: ___________(units______/acre)

6. Total Farm Production in 1998 Long and Short Rains

Crop or Livestock Product	Season	Total Production (Kgs, Ltr)	Total Sales (Kgs, Ltr)	Sale Price (Ksh/unit)	Total Bought (Kgs, Ltr)	Purchase Price (Ksh/unit)
1.	Long					
	Short					
2.	Long					
	Short					
3.	Long					
	Short					
4.	Long					
	Short					
5.	Long					
	Short					
6.	Long					
	Short					
7.	Long					
	Short					
8.	Long					
	Short					
9.	Long					
	Short					

7.a Production Costs on An Acre of Maize and Alternative Crop

Attribute	Maize	Alternate Crop
Seed Quantity		
Fertilizer Quantity		
Manure Quantity		
Pesticide/Herbicide Quantity		
Tillage costs: Tractor (Hours) Oxen (Hours) Hoe (Days)	__________ __________	__________ __________
Planting costs: Tractor (Hours) Oxen (Hours) Hoe (Days)	__________ __________	__________ __________
1st Weeding (Days) 2nd Weeding (Days)	__________	__________
Fertilizer application (Days)		
Pesticide/Herbicide application (Days)		
Harvesting (Days)		
Bagging (Days)		
Total Transport cost (Ksh)		
Total Marketing cost (Ksh)		
Other costs (Ksh)	__________	__________

7.b. Maize Labor Source, Cost and Availability in 1998 (indicate units of measure)

Activity	Tillage	Planting	Weeding	Harvesting	Shelling	Selling
Days of Family Labor: Adults: Kids (<12yrs):						
Hours of Hired Labor on maize						

* 1=Family; 2=Hired; 3=Both; ** 1=Always; 2=Sometimes; 3=Never

8.a. Input Use (Compute out of 100%):

	Maize	Alternate Crop	Other Crops	Livestock	Total
Family Labor					100%
Hired labor					100%
Fertilizer					100%
Other Inputs					100%

8.b. Family Labor:

Name	Sex	Age	Yrs spent in School	Occupation	Days devoted to maize production activities on-farm	Days devoted to other farm production activities on-farm	Days devoted to off-farm activities
1							
2							
3							
4							
5							

8.c. Total Output for the Year (Quantity or Value):

Attribute	Maize	Alternative Crop	Other Crops	Livestock	Off-Farm Labor	Other Income
Total Output (Kg or Bags)						
Gross Revenue (Kshs)						

9.a. Marketing Channel and Prices

Attribute	Maize	Alternate Crop
Month of main crop harvest		
Month of most crop sale		
How much sold in that month (Kgs or Bags)		
Price Received (Ksh/______)		
Main buyer*		
Current price in 1999 (Ksh/_____): Lowest price in 1998 (Ksh/____): Highest price in 1998 (Ksh/____):		

* 1=Government/NCPB; 2=Trader; 3=Miller; 4=Direct consumers; 5=others

9.b. Access to Support Services & Infrastructure

a. Received extension advise? ( )never; ( )regularly; ( )once in the past 5 yrs;
( ) once in past 10 yrs

a. Major source of your maize advise? ( )MoA agent; ( )other farmers; ( )input seller; ( )NGO;
( )local church; ( )others________

b. Have you received credit for maize production? ( )never; ( )regularly; ( )once in the past 5 yrs;
( )once in past 10 yrs

c. Source of maize credit: ( )AFC; ( )KFA; ( )NGO; ( )Church; ( )Bank; ( )neighbour;
( )others_________

d. Have you received credit for other farm activities? ( )yes; ( )no. If yes, for what _________

e. Source of other credit: ( )AFC; ( )KFA; ( )NGO; ( )Church; ( )Bank; ( )neighbour;
( )others__________

g. How far is your farm from a tarmac road?_______kms; from a murram road?_________kms

h. How far is your farm from a seed/fertilizer dealer? ________kms

i. How far is your farm from a T&V demostration site?_______kms

10. Final Question

i. Would you ever reduce the amount of your land under maize? ( )yes; ( )no

ii. If yes, why? ____

iii. What would you plant instead?______________________________

iv. Would you ever stop growing maize? ( )yes; ( )no

APPENDIX B

1999 Village-Level Survey Questionnaire

ACCEPTANCE TO PARTICIPATE/ RUHUSA YA KUHOJIWA:

Tunafanya utafiti kuhusu umuhimu wa teknolojia ya mahindi kwa kuongeza mazao na mapato kutokana na ukuzaji wa mahindi katika sehemu mbali mbali za Kenya. Tutashukuru kwa usaidizi wako wa habari kuhusu ukuzaji wa mahindi na jinsi sahemu hii inavyojaribu kuongeza na kudumisha ukuzaji wa mahindi.

MAJIBU YAKO NI YA HIARI NAITAWEKWA SIRI KABISA. Baadaye itajumulishwa na habari kutoka sehemu nyingine za Kenya ili kutoa ripoti kuhusu ukuzaji na teknolojia ya mahindi.

1. Location Identification: Complete this section last.

District:	**Village:**
Division:	**Cluster Code:**
Location:	**Date of Interview:**
Sub-Location:	**Name of interviewer:**

b. Respondents Name:______________________

c. Position in village: ( ) area chief; ( ) extensionist; ( ) politician; ( ) business person; ( ) church leader; ( ) other (specify)_____________

2. Village Infrastructure:

Infrastructure	**Is it available in village?**	**If not, how far is it from village?**
Tarmac road	Yes____; No____	__________kms
Murram road	Yes____; No____	__________kms
Tap water	Yes____; No____	__________kms
Electricity	Yes____; No____	__________kms
Hospital	Yes____; No____	__________kms
Grain Silos	Yes____; No____	__________kms
Demonstration site	Yes____; No____	__________kms

3. Village Maize Production Status:

Period/Year	**How much maize produced in the village?**
Before market liberalization (1994)	( )Less than enough; ( )enough; ( )surplus
1994 to 1997	( )Less than enough; ( )enough; ( )surplus
1998	( )Less than enough; ( )enough; ( )surplus

4: Village Institutions:

Institution	**Available in village?**	**If not, how far (kms)**	**% of villagers using this service**
Agricultural credit	( )yes; ( )no		
Govt maize buyer	( )yes; ( )no		
Private maize buyer	( )yes; ( )no		
Maize seed stockist	( )yes; ( )no		
Fertilizer stockist	( )yes; ( )no		
Agricultural extension	( )yes; ( )no		

5. Alternate Crop:

a. Besides maize, list 3 major crops grown in this village in order of importance:
i.______________ii.__________ iii. ______________________

b. Will increased production of the alternate crop identified in (a) require:

i. New markets ( )yes ( )no; iv. More labor ( )yes ( )no;

ii. New credit sources ( )yes ( )no; v. New extension effort ( )yes ( )no;

iii. Better/New roads ( )yes ( )no; vi. Other__________________

6: Prices of Maize and Alternate Crops (Ksh/_____):

Crops	Maize	Crop 2	Crop 3	Crop 3
1998: Sale Price (highest): Sale Price (lowest): Purchase Price (highest): Purchase Price (lowest):				
1999: Sale Price (highest): Sale Price (lowest): Purchase Price (highest): Purchase Price (lowest):				
Where sold in 1998?*				
Who bought in 1998?**				

*1=Within village; 2=Neighbouring village; 3= Urban Market; 4=Export/Import; 5=other___________

** 1=Govt; 2=next door farmer; 3=local trader; 4=trader from outside village; 5=other_____________

7. Average Prices of Selected Farm Inputs (indicate units)

Inputs	**1998**	**1999**
Maize seed: Variety 1________ (Ksh/kg) Variety 2________(Ksh/kg) Variety 3_______(Ksh/kg)		
DAP Fertilizer		
CAN fertilizer		
Urea Fertilizer		
TSP Fertilizer		
MAP Fertilizer		
Pesticide		
Herbicide		
Manual Labor: Ploughing: Weeding: Harvesting:		
Tractor Hire: Ploughing:		
Oxen Hire: Ploughing		
Others:		

8. Village Transport and Proximity to other Markets.

a. Do traders come to the village? ( )yes; ( )no

b. If not, what do farmers commonly use to transport maize to the market: ( )lorries; ( ) tractors; ( )pick/Ups; ( )bicycles; ( )donkeys/animal; ( )on backs/heads; ( )others_____

b. What is the distance and road type from this village to the nearest:

Permanent market: _________kms; Type of road: ( )tarmac; ( )murram; ( )dirt; ( )other

Urban Centre/Town_________kms; Type of road: ( )tarmac; ( )murram; ( )dirt; ( )other

9. Village Labor Supply and Demand for Maize Production

a. What is the major source of labor in this village? ( )family; ( )hired; ( )communal; ( ) others________

b. If hired labor, from where? ( )nearby village; ( )within the village; ( )from a far off; ( ) others________

c. Is there migrant labor into the village? ( )yes; ( )no;

d. Is there migrant labor out of the village? ( )yes; ( )no;

e. Which month does labor demand peak? ___________

f. Is it hard to get hired labor at peak season? ( )no; ( )hard; ( )very hard; ( )impossible

10. Importance of Maize and Maize Technology

a. What proportion of village depend on maize as a **major source of food**?

( ) 0-25%; ( )25-50%; ( )50-75%; ( )75-100%

b. What proportion of village depend on maize as a **major source of cash income**?

( ) 0-25%; ( )25-50%; ( )50-75%; ( )75-100%

c. List major constraints to increasing maize production in this village (in order of importance):

1st ____

2nd ____

3rd ____

4th ____

d. How was the maize produce marketing in the village in 1998 compared to the past?

( ) bad; ( ) fair; ( )good; ( )excellent

e. How was the maize seed marketing in the village in 1998 compared to the past?

( ) bad; ( ) fair; ( )good; ( )excellent

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