FARMER RESPONSE TO PRICE IN SMALLHOLDER AGRICULTURE IN KENYA:

AN EXPECTED UTILITY MODEL

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DISSERTATION ABSTRACT

In this study of farmer behavior in Kenya we shall attempt to answer the following questions: What effect does risk have on farmer behavior? Are farmers efficient in their allocation of scarce resources? What are the bottlenecks that limit agricultural production? Lastly, how responsive are farmers to changes in the price vector?

In order to examine these questions we present a neoclassical model of farmer behavior under conditions of uncertainty, i.e., we assume that rather than maximize income, farmers seek to maximize expected utility. By postulating that the distribution of the random variable, income, is normal, we show that maximizing expected utility is equivalent to maximizing a modified utility function, the arguments of which are expected return and the standard deviation of income.

Such a formulation leads to somewhat different conclusions with respect to economic efficiency than does the familiar profit-maximizing approach. In particular, we show that a farmer will equate the marginal utilities of input use into each of his crops with respect to a given input, rather than equating the marginal value products. Thus, for example, the marginal value product of labor in coffee production would be higher than the marginal value product of labor in cotton production, if the marginal increment to risk of producing coffee is higher than the marginal increment to risk of producing cotton.

The data set which we shall use in estimating this neoclassical model is derived from a survey (conducted by the Kenyan Government) of 1500 farms throughout Kenya. The survey consists of monthly visits to each farm, as well as the collection of data at the beginning and end of the survey period. Among the data collected are all inputs, outputs, inventories, prices, capital values, etc. by crop by farm. Despite its defects, this data-set, both in terms of its inclusiveness and the breadth of its coverage, offers the economist a wealth of information rarely to be found in a less developed country.

This micro-level data set is used in the empirical half of this study to estimate Cobb-Douglas production functions for each of the eight enterprises surveyed--local maize, hybrid maize, coffee, cott tea, pyrethrum, improved dairy, and unimproved dairy. The estimation technique used was instrumental variables with prices and fixed inputs as the instruments. It was necessary to use such a technique in order to avoid the simultaneous-equations bias involved in an ordinary least squares approach.

From these estimates we were ready to provide answers to the questions raised above. We found that while farmers were efficient in the allocation of resources they used, they used too few inputs. This indicates that one of the big bottlenecks in small-holder agriculture in Kenya is lack of credit. We also found that risk played a critical role in farmer decision-making, and that, consequently, the reduction of risk would have large payoffs in terms of increased expected return.

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CHAPTER I

INTRODUCTION

While the government of Kenya has as its avowed goal the creation of a society guided by the principles of "African Socialism," [Republic of Kenya, Sessional Paper No. 10] the means of reaching such a goal are clearly capitalistic. This is especially true in agriculture, where the impetus of policy has been to break down the traditional communalistic organization of the village, and replace it with a system of individually owned small farms.

By adopting a decentralized, market-sensitive organization of agriculture, the government has placed itself in the position of being primarily limited to free market tools in effecting the pace, the spread, the mix, and the quantity of agricultural output. Naturally, the most important of these tools, especially in the short run, are prices--all kinds of prices--input prices, wages, output prices, consumer goods prices, intermediate goods prices, the price of leisure, etc. It is through the judicious use of various policy instruments that affect, directly or indirectly, the prices farmers face, that the government can encourage farmers to behave in such a way as to achieve the goals of the political leadership.

In this context, the present study of farmer behavior in Kenya under conditions of uncertainty becomes particularly appropriate. We shall attempt to answer the following questions: what effect does risk have upon farmer behavior? Are farmers efficient in their allocation of scarce resources? What are the bottlenecks that limit agricultural production? Most importantly, how responsive are farmers to changes in the price vector?

Before discussing in some detail the approach which we shall take, it might be well to review, somewhat briefly, the more traditional approach to the question of supply response. This is not the place to survey that rapidly growing literature [cf. Behrman, Dean, Ady, Krishna, 1967, and Stern for detailed bibliographies of this question]. Rather, we should like to discuss the assumptions upon which most of these studies are based, and the shortcomings entailed in these assumptions.

Almost all of these studies are macroeconomic time-series, and most of them are based on the pioneering work of Nerlove [Nerlove, 1958]. In general this means they estimate equations in which the dependent variable is typically area planted under the crop in question at a given time, while the independent variables include various formulations of the lagged dependent variables, expected price, climatic conditions, and expected values for other economic variables, particularly, prices of substitutes.

The first problem with such a formulation lies in the choice of acreage as the dependent variable. If all other inputs increased in the same proportion as acreage, and if production exhibited constant returns to scale, then the output elasticity would be roughly equivalent to the elasticity of land inputs. In fact, however, other factors of production (particularly those which the farmer must purchase in the marketplace) are not likely to increase in the same proportion as land inputs. Moreover as these inputs are likely to have a high marginal product relative to their price (they are in short supply due to the farmer's limited access to credit) output is likely to increase by a much smaller proportion than does acreage. Thus, to some extent, these studies over-estimate the elasticities of output with respect to price.

Secondly, the whole question of risk is generally ignored, or treated nominally. The importance of risk in the farmer's decision-making process cannot be overstated. Not only are future prices uncertain, but equally important, future output is also highly variable. This is especially true, as we shall see, in Kenya. The presence of risk not only has a critical effect on farmer behavior, but also leads to the misspecification of most supply response functions, since risk enters quadratically into the decision-making process.

The other objections to the macroeconomic approach deal with errors of omission, rather than errors of commission. These studies do not really have that much to tell us about how responsive farmers are, only how responsive they seem to be given the economic conditions they find themselves in. In other words, they tell us nothing about what the price-response would be were some of the constraints upon resource use lifted.[1] Moreover, such studies shed no light at all on the increasingly critical policy problem of urban unemployment. If the flow

[1]Miracle and Fetter [1970] noted, for example, that the observation, so common in the early colonial period in Africa, that there was a backward-bending supply curve for labor, need not be explained by such circumventions as the "target worker" theory [Elkan]. Rather, there was a ready explanation in the fact that staying on the farm was more profitable than working for Europeans. It was only the need for cash due to taxes that forced Africans into wage employment.

of migrants to the city is to be reduced, real wages must rise in the rural areas relative to wages in urban areas [Rempel, Todaro and Harris]. An important question related to agricultural pricing policy then is what are the employment-generating effects of changes in agricultural prices. The present study is intended to meet these objections, and to raise these questions.

There are three primary parts into which this study can be divided:

(1) A descriptive section (Chapter II) which briefly describes the place of agriculture in the Kenyan economy, the ecological and institutional constraints which limit farmers' choices, and the importance of risk to the Kenyan farmer;

(2) A theoretical section (Chapter III) which presents a neo-classical model of farmer behavior under uncertainty, and which derives from this model both conclusions concerning the type of behavior that would imply economic efficiency, and expressions for the supply response to price;

(3) An empirical section (Chapters IV to VII) which (a) describes the data set which we shall use; (b) estimates Cobb-Douglas production functions for the eight most important enterprises in small-scale Kenyan agricultura; (c) examines the proposition that Kenyan farmers are efficient in their allocation of scarce resources; and (d) calculates price responses,

given the production functions estimated in Chapter V, and the theoretical model presented in Chapter III.

The next chapter sets, somewhat more concretely, the stage upon which this scenario is to be played out. In Chapter II we provide a brief overview of the general environment, both physical and institutional, within which the Kenyan farmer lives. We begin with a discussion of the organization of agriculture in Kenya and its importance to the Kenyan economy. In particular, we would like to make clear the distinction between large farms (over twenty hectares) and small farms. Is the latter group of farms, characterized by a mixed subsistence-commercial mode of production, which we will be studying. The second half of Chapter II deals with the effects of the ecological and institutional setting upon farmer behavior. In particular, we will argue that Kenya's great seasonal variability in climatic conditions make agricultural production very risky, and that the rudimentary nature of many markets imposes important constraints limiting the scale of agricultural output.

The theoretical foundation of this study can be found in Chapter III, in which we present a microeconomic model of the farmer as expected utility maximizer. By imposing certain conditions upon the utility function, we are able to derive a family of utility functions which are in consonance with both our intuitive beliefs and prior empirical findings. Given this specification of the utility function, it is possible to derive the first-order conditions for expected utility maximization. Such a formulation leads to somewhat different conclusions with respect to economic efficiency than does the familiar profit-maximization approach. In particular we show that a farmer will equate the marginal utilities of input use into each of his crops with respect to a given input, rather than equating the marginal value products. Thus, for example, the marginal value product of labor in coffee production would be higher than the marginal value product of labor in cotton production, if the marginal increment to risk of producing coffee is higher than the marginal increment to risk in producing cotton.

Most importantly, we show in Chapter III, that by taking the total derivative of the first-order conditions, it is possible to derive dX_i/dP_j, the change in the use of input _i_, given a change in the _j_th price. Note that the elasticities calculated from this expression are based on the assumption that farmers will continue to maximize their utilities as the price vector changes. Secondly, of course, these are marginal elasticities, and really do not pertain for large changes in price. Thirdly, they are predicated on instantaneous adjustment. Lastly, they are short-run elasticities, in that the model deals only with a crop-year, within which both the type and quantity of capital stock is fixed.

We begin the empirical study in Chapter IV with a description of the basic data set which we shall use. The Statistics Division of the Ministry of Finance and Economic Planning of the Republic of Kenya has been conducting annual surveys of a sample of small farms throughout Kenya. It has collected data on 1500 farms from seventeen districts in areas most heavily devoted to agriculture. The survey consists of monthly visits to each farm, as well as the collection of data at the beginning and end of each planting year. Among the data collected are all inputs, outputs, inventories, prices, capital values, debt obligations, non-farm income, subsistence consumption, saving, and the like. The particular year which we shall study, 1969/70, was the second year that this survey had been undertaken. Despite its defects, and they are discussed at some length in Chapter IV, this data-set, both in terms of its inclusiveness and the breadth of its coverage, offers the economist a wealth of information rarely to be found anywhere, let alone in the less developed areas of the world.

In the first half of Chapter V, using an instrumental variables technique, we estimate the parameters of the model presented in Chapter III. These parameters consist of the production elasticities of Cobb-Douglas production functions for each of the eight enterprises we shall be studying--hybrid maize, local maize, cotton, coffee, pyrethrum, tea, improved dairy, and unimproved dairy. In addition to these parameters, we also need estimates of the exogenous variables of the model, the variance-covariance matrix of the random fluctuations in output and price. The second half of Chapter V presents a simple expectational model, and using district-level time series of output and price, estimates this matrix.

In Chapter VI we deal more directly with some of the questions raised at the beginning of this Introduction. Are farmers efficient? How important is risk? What are the effective constraints upon agricultural output? Examination of the marginal value products derived from these estimated production functions indicated that while farmers were efficient in allocating the resources they used, they used too few inputs, particularly those inputs which they had to purchase--capital, hired labor, fertilizers, seeds, etc. This indicates that one of the big bottlenecks in small-holder agriculture in Kenya is lack of credit. We also found that risk-aversion played a critical role in farmers' decision-making, and that consequently, the reduction of risk would have large pay-offs in terms of increased expected return.

In the first half of the last Chapter, we calculate the Kenyan farmer's short-run response to price. The elasticities calculated in Chapter VII indicate that (1) farmers are very responsive to price, (2) risk is a critical component of the farmer's calculations, and that (3) there may be very large labor-generating effects of increased agricultural production. The second half of Chapter VII summarizes our results, offers some indication of what these results imply for rural development strategy in Kenya, and discusses some further lines of research.

CHAPTER II

KENYAN AGRICULTURE: AN OVERVIEW

The purpose of this chapter is to describe the institutional and ecological constraints which affect Kenyan farmer's decisions. In particular, we are interested in describing how climatic and geographical conditions on the one hand, and governmental policies on the other, limit the range of decisions available to the farmer. We shall discuss, in turn, the general setting of Kenyan agriculture, Kenya's great climatic variability, and the marketing and pricing policies which affect farmer behavior.

The first section deals with the role of agriculture within the Kenyan economy. Approximately 40 percent of Gross Domestic Product and 75 percent of total employment are generated by the agricultural sector. Agricultural production in Kenya actually comprises two distinct sub-sectors--large farms and small farms. The former, located in areas which once excluded Africans from owning land, are strictly commercial farms, in that they market most of their output and purchase most of their inputs. The farms in the small farm sub-sector, on the other hand, are in transition from subsistance forms of agriculture to commercial agriculture. They market approximately 40 percent of what they produce, and purchase from 10-20 percent of their labor inputs. It is this latter subsector, within which most Africans earn their livelihood, which will be the subject of the present study.

Section II deals with the effect of the geography of Kenya upon agricultural production and farmer decision-making. In Kenya, the ecological factors which affect agricultural production--rainfall, temperature, and soil type--depend, to a large extent, upon altitude. Since altitude varies widely within Kenya, a large number of crops, techniques, and factor-proportions are evident, ranging from land-intensive temperate crops such as wheat to labor-intensive tropical crops such as tea. These ecological conditions not only exhibit great spatial variety, but are also largely variant from year to year. Consequently, agricultural production is very uncertain. Kenya is subject to periods of drought and periods of flood, and the farmer thus makes his decisions in a very uncertain environment, and any model of farmer behavior must take into account the importance of risk.

The third section deals with the institutional setting, with particular emphasis on marketing arrangements. Of the six crops which we will be studying, three (cotton, dairy products, and maize) have their prices set prior to the crop year. The prices of two others, tea and coffee, are set on the world market, in which Kenyan production plays a very small part. Thus for these five crops Kenyan farmers are price-takers. In addition to the setting of prices, the government limits the scope of farmer decisions in several other ways: acreage limitations and the licensing of the production of such crops as coffee and pyrethrum; the provision of credit for the purchase of inputs; and the imposition of land registration and enclosure.

The fourth section concludes the chapter by drawing out the implications of this setting upon farmer behavior. In particular, we discuss the place of maize as a subsistance crop, the degree of freedom available to the farmer in allocating his resources, and the importance of risk in farmer decision-making.

I. AGRICULTURE IN THE KENYAN ECONOMY

Like most African countries, per capita income in Kenya is low ($140) by international standards. However, the post-independence period has produced a record of steady, if not spectacular, growth. From 1964 to 1969, Gross Domestic Product at Factor Cost rose from 330.94 million pounds Kenyan to 449.93 million pounds at constant prices, an average annual increase of 6.3 percent [Statistical Abstract, p. 13]. During the same period, 1962 to 1969, however, population rose by an average annual rate of 3.9 percent [Economic Survey, pp. 4-7]; thus, per capita income rose only by an annual rate of 2.4 percent.

A sectoral breakdown of GDP is presented in Table II-1. As can be seen from the table, 24.7 percent of GDP is estimated to originate outside the monetary sector. If we add to this the value of the agricultural product which is marketed, we can see that the rural sector produces 39.7 percent of Kenya's Gross Domestic Product. But this, in many ways, understates the importance of the agricultural areas to the national economy. Agricultural products accounted for about sixty percent of total export value in 1967 [Development Plan, 1970-1974, p. 191], and, as estimated by the IMF, employed about 1.2 of Kenya's 1.6 million families in 1966 [International Monetary Fund, p. 142]. While economic

TABLE II-1

GROSS DOMESTIC PRODUCT--1968

Percentage of total gross product at Constant Prices

A. Outside Monetary Economy	
Agriculture	20.5
Other	4.2
B. Monetary Economy	
Agriculture	14.5
Manufacturing	9.9
Construction	2.8
Transport	9.3
Wholesale and Retail Trade	9.6
Other	13.9
C. Government	13.9
D. Private Households	.9
Total Gross Product	100.0

Source: Statistics Division, Ministry of Finance and Economic Planning, Republic of Kenya, Statistical Abstract, 1970, p. 33.

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development is not synonymous with agricultural progress, it will be impossible for Kenya to achieve any of its economic goals (universal freedom from want, disease, and exploitation; equal opportunity for advancement; and high and growing *per capita* incomes, equitably distributed among the population) without considerable growth and modernization of its rural society.

This has been recognized in the Second Kenyan Development Plan (1970-1974) which has gone to great lengths to increase public inputs into the rural sector. "The key strategy to this plan is to direct an increasing share of the total resources available to the nation towards the rural areas. The government believes that it is only through an accelerated development of the rural areas that balanced economic development can be achieved, that the necessary growth of employment opportunities can be generated, and that the people as a whole can participate in the development process." [Development Plan, p. 2].

II. THE ECOLOGICAL SETTING

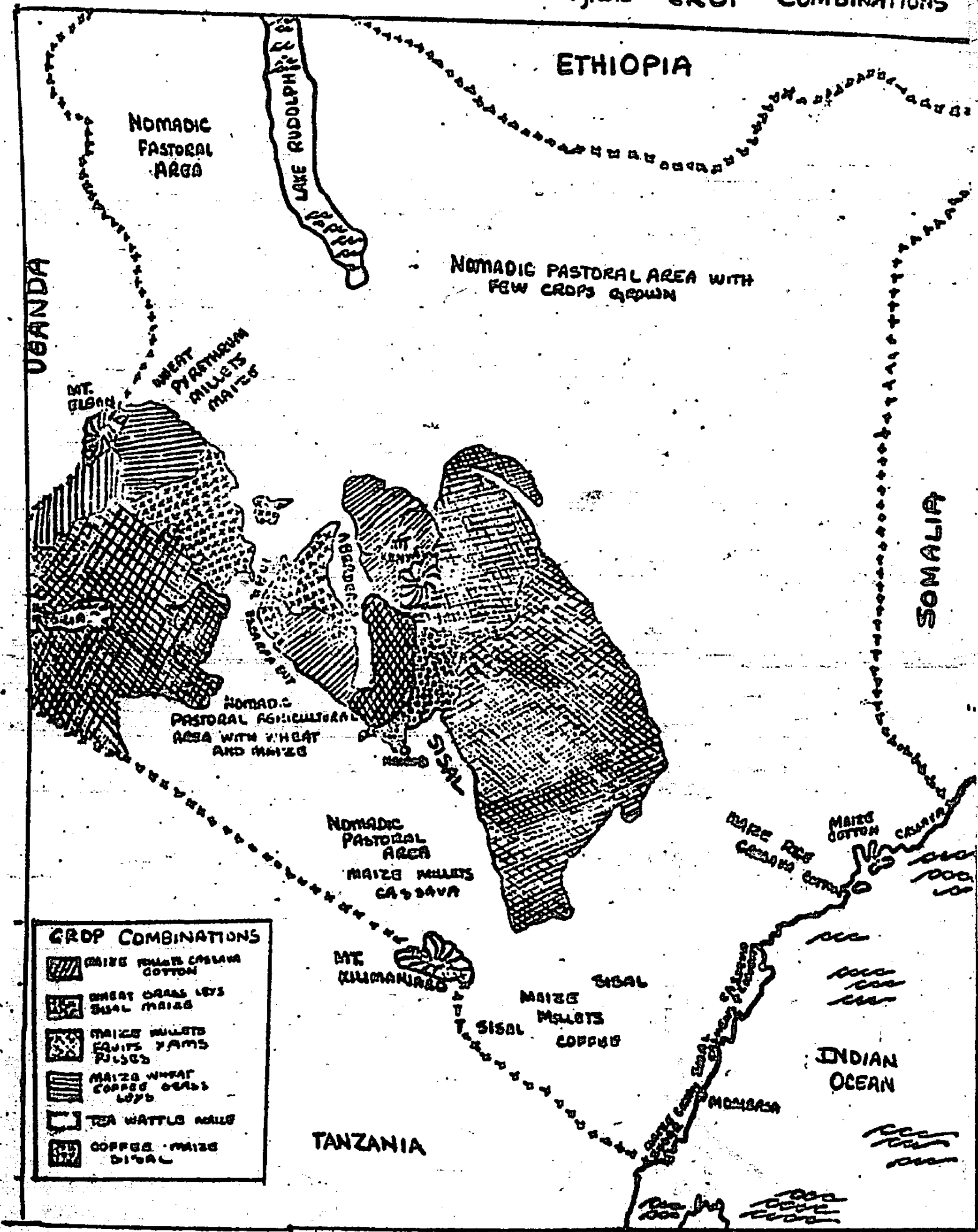
Kenya is situated on the great plateau of East Africa, straddling the equator. The most striking geographical feature is the Great Rift Valley, which bisects the country, dotted by a string of lakes from Rudolph in the North to Magadi in the South. On both sides of the southern half of the Rift rise extremely fertile highlands and grasslands--from Lake Victoria in the West to the areas around snow-capped Mt. Kenya in the central part of the country. To the east and north of the Highlands, the land drops off to a semi-arid scrubland and desert, populated mainly by nomadic pastoralists and wildlife. Along the coast runs another fertile area which is more tropical in vegetation.

There are four main agricultural areas in Kenya (cf. fig. II-1):

(1) <u>The Lake Victoria Littoral</u>

The Lake Victoria region is the most densely populated agricultural area in Kenya. The dominant tribal groups are the Luos in Nyanza Province and the Luhyas in Western Province. Although there is some coffee grown in this area, the main crops are maize and cotton. Per capita income, because of high population density and low cash

Fig. II.1 CROP COMBINATIONS



crop potential, is generally low, although it is supplemented by the wages of the large number of men who migrate to urban areas.

(2) The Rift Valley and Associated Highlands

This area, located to the east of Lake Victoria, ranges in altitude from 5000-9000 feet. Much of this land had been reserved for Europeans during the Colonial period, as the climate is temperate and the area is suitable for large-scale farming of grains such as wheat and maize. The indigenous population, the Kipsigis, Nandi, and Gusii, were originally pastoralists, but have since taken to growing a large variety of crops, although the temperate patterns of maize, wheat, and livestock products predominate. The Kisii Highlands, lying in the Western part of this region, are the best tea-growing areas in Kenya, although much of the tea grown here is produced on large, European-owned plantations. In addition, coffee and pyrethrum are grown in substantial quantities.

(3) The Central Highlands

The area around Mt. Kenya, home of the Kikuyu and associated tribes, is the most developed small-holder region in Kenya. Although the rugged terrain limits the effective size of the farm, it is here that cash-cropping has achieved its greatest success, with tea, coffee, pineapples, and pyrethrum all grown in abundance. Nevertheless, per capita incomes are limited because of high population densities.

(4) The Coastal Plains

This is the only truly tropical area in Kenya. Here, in addition to tree crops, maize and cotton are grown. While population density isn't as high as in some other areas, the opportunities to grow the more profitable crops of coffee and tea are lacking, and agricultural income in the coastal areas is relatively low. District level data, on agricultural income and factor-use, derived from the Small Farm Sample Cost Survey, 1969-1970, are presented in Table II-2.

In Kenya, temperature and rainfall depend mainly on altitude. Thus, areas relatively close together can have widely divergent climates and agricultural potential. In the Central Province District of Murang's, for example, land below 5500 feet, Star Grass areas, have a climate suitable for coffee, while land above 5500 feet, Kikuyu Grass zones, are also suitable for tea and pyrethrum.

These ecological conditions not only exhibit great spatial variety, but also are largely variant from year to year. At least one year in ten is a flood year, and two years in ten have, at least, locally severe drought (cf. Table II-4 for annual rainfall data). Thus maize, the basic subsistance crop, is in surplus one year and in deficit, another. Table II-3 presents the annual trade balance of maize from 1960 to 1969.

It is this great uncertainty with respect to weather conditions, particularly as it affects the subsistance crops of maize and dairy products, that makes resource allocation decisions so difficult for farmers in Kenya, and makes inappropriate any study of this decision-making process which fails to take into explicit account the question of risk.

The risk problem is compounded by the nature of maize marketing in Kenya. Both the selling and buying price of maize are fixed at the

TABLE II-2

MEAN FARM-LEVEL DATA FOR MAIN ECONOMIC VARIABLES BY DISTRICT

DISTRICT	TOTAL LAND INPUTS (acres)	TOTAL LABOR INPUTS (man-days)	TOTAL CAPITAL (shs.)	PURCHASED INPUTS (shs.)	VALUE ADDED (shs.)	FAMILY LABOR (m.d.)	HIRED LABOR (m.d.)	WAGE RATE (sh/d)	PRICE OF LAND (sh/acre)	HIRED LABOR / TOTAL LABOR (%)	VA/L (sh/man-day)	VA/LAND (sh/acre)	PROFIT RATE (%)	SUBSISTANCE CONSUMPTION (%)	LABOR/LAND (man-day/acre)	NET INCOME WITH NON-FARM (sh.)
Lake Victoria Littoral																
Kisumu	4.69	851	3279	20	747	760	92	2.35	443	10.3	0.88	159	13.4	77.2	181	2008
Siaya	9.10	441	868	18	497	394	47	2.00	335	10.7	1.13	55	12.8	76.5	49	1270
Bungoma	17.98	941	1514	535	1264	843	88	1.73	349	10.4	1.34	70	15.9	78.8	53	1871
Busia	14.09	636	1404	123	520	562	74	1.51	249	11.5	0.82	37	10.2	54.5	45	678
Rift Valley																
Kisii	4.60	845	1434	67	837	787	68	3.93	793	5.3	0.99	182	16.8	51.8	183	1112
Kericho	14.78	580	6398	395	1903	402	178	1.19	707	30.8	3.28	129	11.5	49.0	39	2824
Nandi	13.43	434	4006	191	1471	389	45	1.34	322	9.7	3.38	109	17.8	64.4	32	1858
Central Highlands																
Nyeri	5.53	476	1983	233	883	394	82	2.93	1008	17.2	1.88	162	17.7	75.2	86	1213
Murang'a	2.70	474	1280	112	274	447	27	2.19	978	5.6	0.58	101	7.1	38.9	176	566
Kiambu	12.86	623	2989	828	3064	458	165	2.32	1070	26.4	4.92	107	11.7	18.2	49	3497
Kirinyaga	5.33	315	2796	60	963	308	7	2.60	1020	2.2	3.06	181	17.6	84.0	59	1198
Embu	5.54	420	1164	108	650	354	66	2.20	716	18.6	1.55	117	13.5	79.5	76	910
Meru	8.56	713	1439	170	1170	618	95	2.65	333	15.4	1.64	137	27.1	38.4	83	1569
Coastal Plain																
Kilifi	6.18	564	2716	243	138	518	46	1.38	187	10.8	0.24	22	3.2	42.0	91	205
Taita	5.71	1094	6459	866	603	636	454	1.96	970	41.8	0.55	115	5.0	85.0	192	3934

Source: Ministry of Finance and Economic Planning, Statistics Division, Sample Small Farm Costs Survey, 1969-1970 (unpublished).

TABLE II-3

NET EXPORTS OF MAIZE, 1960-1969

Year	Exports (metric tons)	Imports minus Reexports	Net Exports
1960	9348	26	9322
1961	183	102130	-101947
1962	60165	25590	34575
1963	87392	-36	87428
1964	895	264	631
1965	172	81452	-81280
1966	2	143444	-143442
1967	79845	73	79772
1968	277514	39	277475
1969	140768	63	140705

Source: Statistical Abstract, 1970, pp. 45, 57.

TABLE II-4

VARIATION OF ANNUAL RAINFALL

District	Long Period Mean	Number of years in 35-year period when annual rainfall varied from long period mean				
	inches	less than 50%	50-75%	75-125%	125-150%	more than 150%
Kericho	72.93	0	1	31	2	1
Kakamega	72.59	0	1	32	2	0
Sotik	53.69	0	1	33	1	0
Kiambu	50.17	1	5	23	3	3
Bungoma	48.98	1	1	30	2	1
Nandi	43.78	0	1	31	3	0
Nyandarua	41.03	0	5	25	5	0
Nyari	36.83	1	5	25	3	1
Meru	35.56	1	7	22	3	2
Murang'a	33.03	1	6	24	4	0
Taita	25.16	1	10	15	7	2
Nakuru	23.63	0	6	23	4	2
Average		0.5	4.08	26.17	3.25	1.0
Percentages		1.4	11.7	74.8	9.3	2.9

Source: National Atlas of Kenya (Nairobi: Government Printer, 1972), p. 18.

beginning of the crop year. Because of the substantial costs of marketing and distribution, there generally exists a large wedge between the price at which a farmer can sell his maize, and the price at which he can buy it.[1] In general, under conditions of certainty, the most efficient allocation of his resources leads him not to enter the market at all, producing just that quantity of maize sufficient for his own needs [Karani]. However, as the output of maize is a random variable, he will normally plant more maize than he will, on average, require, in order to ensure a supply of maize for his consumption needs should it be a bad year.

Maize policy is critical because it is the staple crop in Kenya. In most areas, no matter what other crops the farmer grows, he will be growing maize for his own needs. It is estimated that about 95 percent of all maize grown on small farms never reaches the market, but is consumed on the farm. It seems clear that the current two-price maize policy increases the risk the farmer must bear, and thus, in order to lower risk, farmers are likely to make choices which trade off expected return for risk. The next section discusses the institutional arrangements which affect the farmer's relationship with factor and product markets.

III. INSTITUTIONAL SETTING

Tenure Patterns. Kenya's enclosure movement began in 1955. Prior to that time, tenure was accorded in consonance with traditional laws.

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[1]Such policy is not limited to Kenya. For an example from Rhodesia, cf. Massel and Johnson [1968].

Among the pastoral Masai, for example, all land was held in common, and individual ownership was unthinkable, while the Kikuyu had a century-long history of individual ownership of arable land, with communal ownership of grazing land [Maina]. For many reasons, mostly political, the Colonial government began moving toward consolidation and registration of individual land holdings, and enclosing common lands in areas of high population density, tribal receptivity, and high cash crop potential. This policy was continued and accelerated by the Kenyatta Government.

During the first ten years of the program (1956-1965), 700,000 hectares of land were registered, mainly in Central Province [Development Plan, 1970-1974]. After a study by a mission of inquiry headed by Mr. J. C. D. Lawerence, it was decided to speed up this consolidation and registration by streamlining procedures. The planned areas of registration are listed in Table II-5. As can be seen there are still

TABLE II-5. AREA OF LAND REGISTERED BY PROVINCE, 1968/69

Province	Area Registered ('000 hectares)	Arable Area ('000 hectares)	Percent Registered
Central	378.3	586.3	62.8
Eastern	188.0	839.7	22.4
Rift (Nandi and Kericho)	61.0	414.1	14.8
Western	331.5	722.7	45.8
Nyanza	74.2	1091.0	6.8

Source: Column 1--Statistics Division, MFEP, Economic Survey, 1970, p. 75;
Column 2--Statistics Division, MFEP, Statistical Abstract, 1970, pp. 82-83.

In addition to land registration, the post-Independence Government began a large scale resettlement scheme--the purchase and distribution to African farmers of about one million acres of formerly European-owned land in the "White Highlands." In point of fact there were two resettlement schemes--a high density one which was mainly directed towards settling the large number of landless Africans created by enclosures in Central Province, and a low density program, whose goal was to create Kulak class of African farmers using modern techniques and earning about one hundred pounds Kenyan ($280) per annum. By 1970, the government had succeeded in creating in many parts of Kenya an agriculture organized into individually owned plots, where, presumably, hard work and a Puritanical work ethic could combine to generate development of small-holder agriculture.

Marketing and Prices. Initiative and hard work will avail little, however, if opportunities for making profits are non-existent. Of prime importance to rural development is the creation of a marketing structure which provides the farmer with the right price signals in allocating scarce resources. For many historical reasons, marketing institutions are pervaded by government laws, restrictions, and organizations. Figures II-1 presents, in schematic form, the progress of agricultural production from farm to consumer.

Maize. While maize is the most important commodity produced on small farms, a large proportion (95 percent) is never marketed [Who Controls Industry in Kenya, p. 1]. Of the total quantity of marketed maize, fifty percent is produced on large farms. All maize must be marketed through the Maize and Produce Board which has statutory power to store,

FIGURE II-4 KENYA'S AGRICULTURAL CROPS

Patterns of Control in Production, Processing, and Marketing, 1967

CROP	PRODUCTION	MARKETING	PROCESSING	DISPOSAL	STATUTORY CONTROL
DAIRY PRODUCE	Small Farms 34 % → Co-operatives Large Farms 66% → Kenya Co-operative Creameries, Ltd. (K.C.C.)	Co-operatives Kenya Co-operative Creameries, Ltd. (K.C.C.)	Other Processors Direct Sales Kenya Co-operative Creameries (93% of sales)	Domestic Consumption K.C.C. Exports worth 2½ million pounds per annum	Kenya Dairy Board
PYRETHRUM	Small Farms 85% → Co-operatives Large Farms 15% → Private Sale	Co-operatives Private Sale (100% →)	Only factory owned by Pyrethrum Processing Company of Kenya, Ltd.	Pyrethrum Marketing Board → Export Market; Local Market	Pyrethrum Board of Kenya Pyrethrum Marketing Board
COTTON	Small Farms 100 % → Co-operatives; Direct Sale Large Farms nil	Co-operatives Direct Sale	Cotton Ginneries all privately owned	Local Market Export Market	Cotton Lint and Seed Marketing Board
COFFEE	Small Farms 60% → Producer Co-operatives Large Farms 40% → Private Sale	Producer Co-operatives → Co-op Factories Private Sale → Kenya Producer Coffee Union mills	Co-op Factories ↓ Kenya Producer Coffee Union mills owned by producer co-op	Coffee and Marketing Board ↓ Public Auction ↓ International Dealers	Coffee and Marketing Board

Figure II-1 KENYA'S AGRICULTURAL CROPS (continued)

CROP	PRODUCTION	MARKETING	PROCESSING	DISPOSAL	STATUTORY CONTROL
TEA	Small Farms 22% →	Kenya Tea Development Authority (KTDA) ⇒	Factories owned by KTDA with growers and tea companies	} → 10-20 % local → 80-90% export through private companies and brokers	Tea Board of Kenya
	Large Farms 78% ⇒	Direct ⇒	Company Factories		
MAIZE	Small Farms 30-40 % →	Maize and Produce Board and Agents	67 mills (50% of all milling)	} → Home Consumption → Strategic Reserve → Export (1½ million pounds, Kenyan, 1967)	Maize and Produce Board
	Large Farms 60-70 % ⇒	Maize and Produce Board and Kenya Farmers Association	Kenya National Mills, Ltd. (50 % of all milling)		

Source: <u>Who Controls Industry in Kenya?</u>, pp. 10-11 distribute, purchase, and sell maize and other produce [Who Controls..., p. 2]. It enlists regional produce boards as its agents in buying maize, sends the maize to millers, and fixes their profit margins. Producer prices are fixed before each planting year by the Minister of Agriculture, and are subject to the Marketing Board's costs of transportation and distribution. Consumer prices for maize and maize meal are fixed by the Price Control Ordinance [Chapter 504 of the Laws of Kenya]. However, a large black market exists, especially in Western Kenya, and it is estimated that some 100,000 bags of maize are illegally sold in Uganda annually [Report of the Maize Commission of Inquiry, p. 51].

Coffee. Unlike maize, there are no coffee price supports. However, in 1963 Kenya joined the International Coffee Agreement, and has subsequently refused to allow any further expansion of coffee acreage. All coffee grown on small farms is sold to producer co-operatives who process the coffee and sell it to the Kenya Coffee Marketing Board. This board then sells the coffee at weekly auctions in Nairobi, averages the prices over the year, deducts operating costs and a one percent tax for research purposes, and pays the co-operatives on the basis of quality. There is some distortion of relative grade prices--penalizing lower grade coffee and rewarding the better grades [Westlake and Smith].

Tea. The production of tea has spread rapidly throughout the smallholder sector. The Kenya Tea Development Authority was created in 1964 to organize and develop the production of tea among African farmers. Smallholder production of tea has risen from 1.6 percent of total Kenyan tea production in 1961 to 16.7 percent in 1968 [Statistical Abstract, 1970, p. 69]. The KTDA processes the tea through its factories, and then sells it to agents who market it in London. The Kenya Tea Board supervises the licensing and regulation of tea growing and processing, and undertakes "research into all matters relating to the tea industry" [Cap. 343 of the Laws of Kenya]. Like coffee, the price of tea is determined by the world market.

Pyrethrum. Kenya is the world's largest producer of pyrethrum, a flower from which pyrethrin, a powerful insecticide, is extracted. It has also "became the first, and thus far only, significant crop once grown predominately by Europeans where Africans now produce more than half of total output." [Development Plan, 1970-1974, p. 69]. Much of the control in this enterprise is directed toward licensing production and controlling output so as to keep prices high. According to the Pyrethrum Act of 1964, control is vested in a Pyrethrum Board appointed by the Minister of Agriculture "to license pyrethrum growers according to the annual quota determined by the Marketing Board," and a marketing board, also appointed by the Minister of Agriculture to determine the quote of pyrethrum flowers to be produced annually, purchase all pyrethrum flowers, control processing, and export pyrethrum extract. Prices paid farmers depend to a large extent on the amount produced in Kenya.

Cotton. Cotton is only grown by small farmers, in Western Kenya, and along the Coast. Marketing is the responsibility of the Cotton Lint and Seed Marketing Board, which purchases cotton from growers through its agents, at a fixed price set each year by the Minister of

Agriculture. Most cotton is exported, but a large proportion is also marketed domestically. Cotton ginneries are owned privately, and are ensured a fixed return.

Milk. In 1958 the Kenya Dairy Board was established with the following functions: (1) Organization, regulation, and development of efficient production; (2) improvement of the quality of milk; and (3) stabilization of producer prices [Klemm, p. 3]. The KDB purchases its milk through its agent, the Kenya Co-operative Creameries, Ltd., a co-operative society which now has a majority of African members, and which handles 93 percent of dairy product sales [Who Controls Industry in Kenya, p. 36]. The price structure for milk is extremely complicated and variegated, depending on geographical location and the producer pool the farmer is associated with. The highest price is paid to quota milk, primarily milk for human consumption. In order to enter this pool a farmer has to maintain a constant supply of milk throughout the dry season. Any additional milk production above his quota can be sold into the second pool (the contract pool) at a lower price. Contract milk is used to satisfy the manufacturing requirements of the dairy industry, and a producer is allowed to fall 25 percent below his contract without being penalized. The lowest price milk is separated for cream, and is a residual after the first two obligations have been met [Klemm, pp. 18-19].

African farmers sell their milk to co-operatives which in turn sell to the KCC. As in most other agricultural commodities, the farm-gate price depends on the efficiency of distribution and marketing of these middlemen, as well as on transportation costs.

Factor Markets: As we have already noted, there are four primary factors in agricultural production--land, labor, capital, and purchased inputs. Of these land, most labor, and some capital can be classified as traditional inputs, that is, inputs owned by the farmer, for which there are few markets; the rest are modern inputs, and their availability depends on the marketing structure. This distinction is made more for heuristic than analytical reasons. We should now like to discuss both of these two groups in somewhat greater detail.

(1) Traditional Inputs: As can be seen in Table II-2, the bulk of the inputs into agricultural production can be classified as traditional, non-marketed inputs. Unfortunately, this implies that to some extent, at least, the total volume of agricultural inputs are limited. Certainly, in the short-run (crop-year), the supply of such traditional factors as capital (native grades of livestock, buildings, some tools), and land are fixed. This is not as true of family labor, which as we shall see, is in surplus (especially in the slack seasons). A large proportion of farm households, especially in densely populated areas, earn sizable incomes off the farm. Thus, while changes in output and input prices are not likely to effect the total quantity of land and capital used, they could lead to the increased employment of family labor in rural areas.

(2) Modern Factors: Somewhere between ten and twenty percent of all labor inputs on small farms are purchased on the market (Table II-2, Col. 10). Unfortunately, annual data do not tell the whole story, as

most of these inputs are purchased during peak seasons. Since, in any region, harvesting and planting will take place at basically the same time, and since tribal prejudices tend to discourage in-migration of workers from areas which may be experiencing slack seasons, it may be that the total quantity of hired labor available to farmers during periods of peak demand is limited [Ominde].

For other inputs, markets are better articulated, although there are indications that some degree of monopoly prevails [Maize Commission of Inquiry]. The real problem facing the ambitious farmer, that is, the farmer who is attempting to expand production or undertake innovations and upgrading of his capital stock, is the scarcity of short-term and medium-term credit. Agricultural credit in Kenya, in accordance with the policy emphasis given to enclosure, resettlement, and land registration has largely been directed toward long term loans for land purchase. Loans of the medium term for capital equipment (especially for modern breeds of dairy cattle), and for the crop year for current expenses such as fertilizer and wages, have been given short shrift, though this pattern has been changing slowly (cf. Table II-6.

As we shall see this limited capital availability constitutes one of the most important bottlenecks to increased agricultural production.

TABLE II-6. PATTERNS OF CREDIT, 1964-1968

Year	Long Term Kenyan Pounds	Long Term Percent of Total	Short Term Kenyan Pounds	Short Term Percent of Total	Total Kenyan Pounds
1964	1233000	57.9	895762	42.1	2128762
1965	1130000	54.1	961193	45.9	2091172
1966	655000	56.4	506360	43.6	1161360
1967	98000	25.0	295557	75.0	393557

Source: Statistics Division, Ministry of Finance and Economic Planning, Republic of Kenya, Statistical Abstract, 1970, pp. 118-119.

IV. CONCLUSIONS

We have discovered that due to climatic conditions, agricultural production in Kenya is an inherently risky undertaking. This risk has been compounded by the dual pricing policy for maize which leads most farmers to attempt to produce just that amount of maize which will feed their family. However, the same environment which makes agricultural production so uncertain, provides the type of climate which permits farmers to grow a variety of crops. And it is this ability to grow more than one crop in a given area which allows farmers to reduce risk in much the same way that a wealth-holder reduces risk by diversifying his portfolio.

We have also learned that the farmer's choices are limited by institutional and marketing arrangements; that, for example, no new plantings of coffee or pyrethrum are allowed without a license, and that most domestic prices are set prior to the crop year. Most importantly, we have seen that credit scarcity limits, to some degree, the scale of agricultural output. The next chapter details a model of farmer behavior under conditions of uncertainty, using the information we have just outlined.

CHAPTER III

A NEOCLASSICAL MODEL OF FARMER BEHAVIOR IN KENYA

In this chapter we shall present a model of farmer behavior in Kenya, incorporating explicitly the question of risk. By using the neoclassical approach to the problem of decision-making under uncertainty, we derive first-order conditions for expected utility maximization, calculate price-responses, and derive a pair of hypotheses which permit us to test the general specification of the model.

Accordingly, Section II presents a neoclassical model of decision-making under uncertainty, and demonstrates, that, given both a utility function with nice properties, and the probability distribution of the random variable, income, we have all the information necessary to determine the allocation of resources that will maximize expected utility.

We then set out, in Section III, to generate reasonable specifications of the utility function and of the probability distribution of income. Considerations involving the property of decreasing absolute risk aversion lead us to specify that the utility function have a semi-logarithmic form. Similarly, analytic simplicity, and the desirability of having a probability distribution completely described by its first two moments, lead us to assume that the distribution of income is normal.

Section IV contains the mathematical heart of this chapter. Using a semi-logarithmic utility function and a normal distribution of income, conditions for the maximization of expected utility are generated. It is these first-order conditions for expected utility maximization which form the econometric model which we will later estimate.

Sections V and VI are direct results of the maximization conditions generated in the analytical section. In the former, we derive testable hypotheses concerning rational behavior and economic efficiency. Given our model, we show what relationships should pertain among the marginal value products of any set of inputs across crops, if farmers behave in an efficient manner. In the latter we calculate price-response equations by totally differentiating the first-order conditions.

The last section discusses the links between the analytical material presented in this chapter, and the econometric study that is to follow. There are three steps in this econometric procedure:

(1) estimating the model

(2) testing the model

(3) calculating the supply-response elasticities

These three tasks will be the subject of the second half of this study.

II. A NEOCLASSICAL MODEL OF FARMER BEHAVIOR UNDER CONDITIONS OF UNCERTAINTY

As Tedford has noted [p. 1354], basic decision questions are trivial in a world of certain outcomes. But the world is uncertain, especially for a Kenyan farmer, for whom the next year may bring drought or flood, locusts or coffee berry disease, rising prices or falling prices. The role of uncertainty in farmer decision-making in developed countries is at least paid lip-service, although the bulk of the literature in this field deals with programming methods and simulation studies [Hazell, Hildreth, and Sadan]. The few exceptions include surveys undertaken to test whether or not the farmer is risk-averse. Few attempts have been made to estimate the parameters of a behavioral model.

In the development literature even less is known. Countless writers have acknowledged the importance of risk-aversion in understanding the behavior of "conservative peasants" [Massell and Johnson; Mellor, 1966; and Schultz], but few attempts have been made to measure this risk aversion and assess its impact. Both Kunreuther and Behrman, in the context of supply-response studies in Asia (Bangladesh and Thailand, respectively) have included risk as a variable in their equations, and both have found its impact to be substantial. There have also been attempts to model farmer behavior in a game-theoretic framework [Falcon].

Decision theory offers a number of alternative approaches to modelling this problem [Tisdell]. In the context of Kenyan agriculture there seems to be no evidence supporting one of these theoretical models over another. Accordingly, we shall choose that approach which seems to be most in consonance with the vast body of economic literature over the past century--the neoclassical model.

This is not the place to outline the development of the neoclassical model of behavior under conditions of uncertainty but its main features can be outlined briefly [cf. Arrow for bibliographic and historical information]. The decision-maker is seen to have a utility function with one argument, income, which is, itself, a random variable with a known distribution. The decision rule, which is to maximize expected utility, can be derived from a set of more basic assumptions relating to the transitivity and continuity of the utility function [Von Neumann and Morgenstern].

For example, let us consider the choices facing the farmer in Kenya. He possesses a set of resources (land, labor, and capital) that can be used as inputs into a set of production processes, each of which has an uncertain outcome. Thus, a farmer, for whom risk is an important consideration, will maximize his expected utility rather than his expected income. If his utility function is specified, and if the joint distribution of the random variables is known, it is conceptually a relatively simple problem to arrive at that allocation of resources which is optimal. Unfortunately, what is simple conceptually, is not always as simple analytically, and the next section will be devoted to limiting the specifications of both the utility function and the distribution of income to forms that both lead to behavior that is consistant with empirical evidence with respect to Kenyan agriculture, and are also analytically tractable.

III. A MORE CONCRETE DECISION-MAKING MODEL

Let us begin with the utility function. We will specify that it be continuous and twice differentiable. We shall also assume that the marginal utility of income to be positive, but decreasing, as income increases. Thus, $U' > 0$ and $U'' < 0$. The third characteristic which will help limit the family of acceptable utility functions is that of risk aversion. We can define risk aversion as the amount of an insurance premium an individual would be willing to pay in order to ensure a safe outcome. We can speak of absolute risk aversion, that is, the amount of the insurance premium, R, and relative risk aversion, R*, which is the proportion of an individual's income he is willing to pay as an insurance premium. Arrow [1965] has shown that

(3.1) $R = -U''/U'$

(3.2) $R^* = -YU''/U'$ where Y = income

Clearly, any utility function for which $U' > 0$, $U'' < 0$, will exhibit positive risk aversion. Of greater interest, is whether these measures of risk aversion, R and R*, are increasing, constant, or decreasing functions of income. For example, if absolute risk aversion increases as income increases, then as a person moves from lower to higher levels of income he'd be willing to pay a higher insurance premium for the same amount of insurance. This seems counter-intuitive, especially with regard to peasants in less developed countries. The development literature abounds with references to conservative peasants unwilling to adopt new techniques because of the uncertainty connected with them [Mellor, 1966, Hildreth; and Tadros and Casler]. Surely, at very low levels of income farmers are more interested in insuring survival than in taking unnecessary chances in order to increase expected return. We would then argue that the utility function we specify should exhibit decreasing absolute risk aversion.

What can we say about relative risk aversion? Arrow shows that relative risk aversion is increasing, constant, or decreasing as the income elasticity of the demand for cash balances is greater than, equal to, or less than unity. There are several empirical studies for the United States which suggest that this elasticity is considerably greater than unity, and thus inferentially, that increasing relative risk aversion is a property of utility functions in the United States [Seldon; Friedman; and Meltzer]. However, there is no evidence of similar behavior among small-scale farmers in Kenya. We have no a priori grounds for restricting relative risk aversion to be increasing, constant, or decreasing.

To recapitulate, then, we will specify a utility function that is continuous, differentiable, with the first derivative positive and the second derivative negative, and which exhibits the property of decreasing absolute risk aversion. Pratt suggests several families of utility functions that fit this specification, but by far the most useful, because of its analytical simplicity, is the semi-logarithmic function:[1]

$$(3.3) \quad U = \ln(Y)$$

For reasons listed above, we will assume that farmers in Kenya have equation (3.3) as their preference function.

---

[1] Among the family of utility functions exhibiting decreasing absolute risk aversion are:

$$U(x) = (x+d)^q \quad \text{where} \quad d \geq 0,\ 0 < q < 1$$
$$U(x) = -(x+d)^{-q} \quad \text{where} \quad d \geq 0,\ q > 0$$
$$U(x) = \log(x + d + (x+d)^2 + b) \quad d \geq |b|^{1/2}$$
$$U(x) = \arctan\ (ax + b) \quad \text{where } a > 0,\ b > 1$$

As we stated in Section II, given U, one only needs the distribution of Y, the random variable, in order to have all the information necessary to allocate resources rationally. Suppose, for example, there are two crops whose physical outputs, Y_1 and Y_2 respectively, are given by the following production functions:

$$(3.4)\quad Y_1 = f(X_1, X_2, X_3)\,\gamma_1$$

$$(3.5)\quad Y_2 = g(X_4, X_5, X_6)\,\gamma_2$$

Let us further assume that all inputs, X_i, $i = 1, 2, \ldots, 6$, are owned by the farmer, and that the prices of the two crops are given by $P_1\delta_1$ and $P_2\delta_2$, respectively. Then income, Y, is given by

$$(3.6)\quad Y = P_1 f(X_1, X_2, X_3)\,\gamma_1\delta_1 + P_2 g(X_4, X_5, X_6)\,\gamma_2\delta_2$$

with γ_1, γ_2, δ_1, δ_2 all positive.

The variables γ_1, γ_2, δ_1, δ_2, are all random variables with mean, 1. We are thus specifying that outputs Y_1 and Y_2 are made up of stochastic and non-stochastic parts, and that the expected values of Y_1 and Y_2 are given by:

$$(3.7)\quad E(Y_1) = \bar{Y}_1 = f(X_1, X_2, X_3)\ ;\ E(Y_2) = \bar{Y}_2 = g(X_4, X_5, X_6)$$

Similarly, the expected prices are:

$$(3.8)\quad E(P_1\delta_1) = P_1 \quad ; \quad E(P_2\delta_2) = P_2$$

We will also assume that γ_1 and γ_2 are both independent of δ_1 and δ_2; in other words, the random disturbance that affects price has no effect on output, and conversely.[2]

---

[1] Only in the case of pyrethrum is this assumption questionable, for reasons that have already been explained in Chapter II (pp. 22-27).

What is a reasonable assumption for the joint distribution of γ_i's and δ_i's, $i = 1, 2, \ldots, n$? Since their range is limited to positive values, and since the mean is unity, it would seem reasonable to assume that these random variables are distributed log-normally, i.e., normal distributions of the logarithms of the random variables.[3] This presents a very serious problem, since the joint distribution of a linear combination of log-normal variates (and that is what Y is), is not, in general, known.

At this point, for several important reasons, we will take refuge in the Central Limit Theorem of probability theory, which states that any distribution with finite variance can be approximated by a normal distribution with the same moments [Cramer]. Such an approximation not only provides us with a distribution whose moments are known, but, equally important, the assumption of normality allows us to consider only the first two parameters of the distribution of Y, and considerably simplifies the analytical presentation of the next section [Tobin, 1958]. Readers who are not interested in the mathematical methodology should skip to section V.

IV. THE ANALYTICS OF EXPECTED UTILITY MAXIMIZATION

It will simplify matters considerably if, in the generation of the results that follow, we deal with generalized formulations of both the utility function and the production functions. As we noted above,

[3] cf. Feldstein for a discussion of the relevance of the log-normal distribution in the study of portfolio behavior in the United States.

with a normal distribution of income, maximizing expected utility involves only two parameters of the distribution of income--the mean and the variance. Thus,

$$(3.8) \quad \text{Max } E\,[U(Y)] \text{ is equivalent to Max } U^*(\bar{Y},\sigma_y^2)$$

$$\text{where } U_1^* > 0 \text{ and } U_2^* < 0$$

For the semi-logarithmic function with a normal distribution of Y, maximizing expected utility is given by:

$$(3.9) \quad E(U) = {}_0\int^{\infty} K\ln(Y)\, \exp[-(Y-\bar{Y})^2/\sigma_y^2]\, dY^4$$

This expression can be evaluated by a Taylor expansion of the integral. The resultant function, U*, is given by:

$$(3.10) \quad U^*(\bar{Y},\sigma_y^2) = \ln(Y) - \sigma_y^2 / \bar{Y}^2$$

The resulting partial derivatives are:

$$U_1^* = 1/\bar{Y}+2\sigma_y^2/\bar{Y}^3$$

$$U_2^* = -1/\bar{Y}^2$$

$$(3.11) \quad U_{11}^* = -1/\bar{Y}^2 - 6\sigma_y^2 / \bar{Y}^4$$

$$U_{12}^* = 2/\bar{Y}^3$$

$$U_{22}^* = 0$$

We can also simplify notation somewhat by allowing

$$(3.12) \quad \sigma_{ij} = \text{cov}\gamma_i\gamma_j + \text{cov}\ \delta_i\delta_j + \text{cov}\ \gamma_i\gamma_j\ \text{cov}\ \delta_i\delta_j{}^5$$

Then

$$(3.13) \quad \sigma_y^2 = P_1^2\bar{Y}_1^2\sigma_1^2 + P_2^2\bar{Y}_2^2\sigma_2^2 + 2P_1P_2\bar{Y}_1\bar{Y}_2\sigma_{12}$$

---

[4] Since Y cannot be negative, a constant must be added to $\bar{Y}$ so as to insure that the bulk of the probability is positive, and the expression representing the normal distribution is really a density function.

[5] This is possible because of our assumption concerning the independence of the stochastic elements affecting price and output.

It would also be well to constrain the set of inputs available to the farmer. There are three distinct types of inputs--(1) those, such as family labor and land, for which the total supply is limited, but which can be allocated among crops; (2) those, like fertilizer, which can be purchased on the market; and (3) those, such as tools and coffee trees, which are fixed and non-allocatable. Thus we will assume the following:

(3.13a) $\bar{X} = X_1 + X_4$ total input supply is fixed

X_2, X_5 can be purchased at price P_3

$X_3 = X_6 = \bar{X}_k$ fixed, non-allocatable, capital input

The objective function (in the two-crop case) with all its constraints is given by:

$$(3.14)\quad E[U(Y)] = U^*[(P_1\bar{Y}_1 + P_2\bar{Y}_2 - P_3\ (X_2 + X_5)), (P_1^2\bar{Y}_1^2\sigma_1^2 + P_2^2\bar{Y}_2^2\sigma_2^2 + 2P_1P_2\bar{Y}_1\bar{Y}_2\sigma_{12})] + \lambda_1\ (\bar{Y}_1 - f(X_1, X_2, \bar{X}_k)) + \lambda_2(\bar{Y}_2 - g(K_4, X_5, \bar{X}_k)) + \lambda_3\ (\bar{X} - X_5 - \bar{X}_k)$$

Maximizing (3.14) with respect to the nine choice variables ($\bar{Y}_1$, $\bar{Y}_2$, X_1, X_2, X_4, X_5, λ_1, λ_2, λ_3), and eliminating the λ's, produces the following first-order conditions:

$$
(3.15)\quad
\begin{aligned}
U_1^* P_1 + U_2^* (2P_1^2\bar{Y}_1\sigma_1^2 + 2P_1P_2\bar{Y}_2\sigma_{12}) - U_1^*P_3/f_2 &= 0 \\
U_1^* P_2 + U_2^* (2P_2^2\bar{Y}_2\sigma_2^2 + 2P_1P_2\bar{Y}_1\sigma_{12}) - U_1^*P_3/g_2 &= 0 \\
f_1g_2 - f_2g_1 &= 0 \\
\bar{Y}_1 - f(X_1, X_2, \bar{X}_k) &= 0 \\
\bar{Y}_2 - g(X_4, X_5, \bar{X}_k) &= 0 \\
\bar{X} - X_1 - X_4 &= 0
\end{aligned}
$$

The next section will discuss some of the hypotheses generated by the first-order conditions (3.15); from these hypotheses, tests can be conducted to determine whether Kenyan farmers behave in the manner predicted by our model.

V. RATIONALITY AND ECONOMIC EFFICIENCY IN AN UNCERTAIN WORLD

The conclusions derived from the theory of the firm concerning economic efficiency may be summarized as follows:

If firms act in such a way as to maximize profits, the following conditions must be met:

(1) the marginal value product of any input equals its price and therefore;

(2) the ratio of the marginal physical products of any two inputs equals the price ratio of the inputs,

(3) the marginal value products of any input in two uses are equal.

From the third equation of (3.15) it is clear that the second condition holds in our model. However, we will show that, if the farmer is risk averse, the first and third conditions for profit maximization will not, in general, be true.

Taking the ratio of the first two equations of (3.15) we get

$$(3.16)\quad \frac{(P_1f_2 - P_3)}{(P_2g_2 - P_3)} = \frac{(2P_1^2\bar{Y}_1\sigma_1^2 + 2P_1P_2\bar{Y}_2\sigma_{12})}{(2P_2^2\bar{Y}_2\sigma_2^2 + 2P_1P_2\bar{Y}_1\sigma_{12})}$$

Let us define the following:

$$S_1 = 2P_1^2\bar{Y}_1\sigma_1^2 + 2P_1P_2\bar{Y}_2\sigma_{12}$$

$$S_2 = 2P_2^2\bar{Y}_2\sigma_2^2 + 2P_1P_2\bar{Y}_1\sigma_{12}$$

Then $S_1 = \partial\sigma_y^2/\partial\bar{Y}_1^2$ and $S_2 = \partial\sigma_y^2/\partial\bar{Y}_2$, the marginal increments to risk of increased production of Y_1 and Y_2, respectively. If S_1 is greater than S_2 then crop 1 is riskier than crop 2; in any case we have:

$$(3.17)\quad P_1f_2 \gtrless P_2g_2 \quad \text{as} \quad S_1 \gtrless S_2,$$

i.e., the marginal value product of any input into activity _i_ is greater than, equal to, or less than the marginal value product of that same input into activity _j_, as the marginal increment to risk of increased production of commodity _i_ is greater than, equal to, or less than the marginal increment to risk of increased production of commodity _j_. This result is analogous to that of portfolio-choice theory where investors who choose riskier assets expect higher returns [Tobin, 1965; Markowitz].

In short, a ranking of crops by their marginal increments to risk (S_i) should be identical to a ranking of the marginal value products by any allocatable input. This condition for economic efficiency, coupled with the profit maximization condition of the equality of the ratios of the marginal physical products of any pair of inputs in each of two uses, makes it possible for us to test whether the behavior of the small-scale farmer in Kenya is consonant with the model we have propounded.

VI. THE PRICE RESPONSE OF KENYAN FARMERS

In order to discuss price response it is simpler to change the notation somewhat, and to generalize to n cases, where n equals the number of different input uses. Then in matrix form:

$$(3.18)\quad \bar{Y} = PF(X)$$

$$(3.19)\quad \sigma_y^2 = PFV(FP)'$$

$$(3.20)\quad E(U) = U^*(PF, PFV(FP)') + \lambda\,(\bar{X}I - X_m)$$

where (FP)' is the transpose of the vector PF, the vector of incomes from each crop,

V is the variance-covariance matrix, of which the typical element is σ_{ij},

X_m is the set of vectors of inputs for which the total quantity is fixed,

λ is the vector of LaGrangian variables

The maximization conditions then become:

$$(3.21)\quad U_1^*PF_i + U_2^*PF_iV(F\,P)' + \lambda = 0 \quad i, \text{ constrained}$$

$$U_1^*PF_i + U_2^*PF_iV(FP)' = 0 \quad i, \text{ not constrained}$$

From these maximization conditions, which are identical to those of (3.15), we can calculate the farmer's supply response to price, dX_i/dP_j.

Taking the total derivative of each of the n equations, gives us a set of N equation systems of the following form:

$$(3.22)\quad A dX_i = R_j dP_j \qquad i = 1, 2, \ldots, n$$

$$j = 1, 2, \ldots, N$$

where

$$a_{ij} = U_1^* PF_{ij} + U_2^* (PF_i VF_j' + PFVF_{ij}) + U_{11}^* (PF_i - Q)(PF_j - Q) + 2U_{12}^* ((PF_i - Q)(PFVF_i') + (PF_j - Q)(PFVF_j'))$$

and

$$r_{ij} = -(U_1^* F_i + U_2^* (F_i PFV_i + PF_i F^j V_{ij}) + U_{11}^* F_j PF_i + 2U_{12}^* PF_i PFVF^j)$$

The solution to (3.22) is easily found by use of Cramer's Rule. Substituting R_j into the ith column of A

$$(3.23)\quad dX_i/dP_j = |A'| / \Delta$$

where $|A'|$ is the determinant of the new matrix, and Δ is the determinant of A

It is difficult to show analytically that A is non-singular, but the calculations which we shall perform in Chapter VII indicate that this is, indeed, the case. Needless to say, the resulting expression is quite complicated and ambiguous, since not only are there income and substitution effects to take account of, but also added difficulties caused by the curvature of the production functions. Thus, in order to predict the signs or magnitudes of the farmers' price response, one needs to know the specification and parameters of the utility function, the variance-covariance matrix of the subjective probability distributions of output and price, and the technological relationship between inputs and prices.

VII. ESTIMATING THE MODEL

This section will be mainly concerned with anticipating the econometric study to follow. This study has four components:

(1) The estimation of the variance-covariance matrix

(2) The estimation of the utility maximization model

(3) Testing the model

(4) Calculating the Price Response

We have said little so far of the estimation of the variance-covariance matrix. This is a separate problem from the estimation of the basic model. What we shall do is examine time series of output and price for each of the crops involved, extract the random component of each series, and use these estimates of the disturbances to calculate the variance-covariance matrix. Having done this, the σ_{ij}'s become exogenous variables in the basic model.

The most critical aspect of the empirical portion of this study is the estimation of the model presented in (3.15). The next chapter will examine, in some detail, the data upon which this estimation is to be based. In Chapter V we briefly discuss estimating procedures, and then proceed to estimate those equations of the model which involve the production functions. There are no parameters in the other equations of (3.15) which are not derived from the production function elasticities and constant terms.

Once these production functions have been estimated, it will be possible to test whether farmer behavior is indeed risk averse. As we noted above, if farmers are expected utility maximizers, then we would expect to find all three of the following conditions to hold:

(1) the non-equality of marginal value products of any input in each of its alternative uses;

(2) the ranking of crops by marginal value products, for any input, will be the same as the ranking of these crops by the marginal increment to risk;

(3) within a crop, for any two inputs purchased on the market, the ratio of the marginal products should equal the price ratio.

These three tests will enable us to state whether or not the analytical model presented here adequately describes farmer behavior.

Lastly, by means of equation (3.22) we can calculate the price response elasticities. It might be well to review just what these elasticities do and do not signify. First, these elasticities will not have been estimated directly by any type of regression analysis; rather, they will have been calculated from the estimated production functions and risk matrix for the semi-logarithmic specification of the utility function. Thus, they do not, in any way, represent observed patterns of behavior, but rather expected behavior, if farmers are expected utility maximizers. In other words, if farmers, given current levels of exogenous variables, maximize their expected utility, as we have argued, and if they continue to maximize their expected utility when the exogenous variables change, then the numbers which we shall calculate do indeed represent the short-run elasticities of supply.

There are some further assumptions which should be made explicit before we proceed to derive the results. We have not allowed any adjustment process to take place, assuming that farmers react instantaneously to changes in exogenous variables. This is probably not true, and thus the elasticities which we will calculate are most likely under-estimates of the true results. Secondly, these are short-run elasticities, relating to change within a time period (crop year) during which capital stock on the farm specific to certain enterprises--coffee trees, or unimproved cattle, for example--is fixed. Since these capital inputs are of great importance in the production process, the scope for changing the input mix in the short-run is severely limited. Long-run elasticities would be of much greater interest for policy purposes in any case, but such long-run elasticities require much more information than is available at this time.

CHAPTER IV

THE DATA SETS

Ideally, the model which we will be estimating requires a cross-sectional time series of micro-level data on inputs, outputs, and prices. In this way we would have information on both the cross-sectional model described in Chapter III, as well as on the random variables which affect both output and price across time. Unfortunately, such a data set is unavailable. What we do have is a cross-sectional, farm-level series on inputs, outputs, and prices, and an aggregate time series on marketed output and price to the producer. We intend in this chapter to describe in some detail these data sets, their strengths and weaknesses, and the procedures used to link the available data to the variables specified by the model.

The first section describes the Small Farm Sample Cost Survey, 1969-1970, which is the source of the cross-sectional, micro-level data. Section II deals with the not inconsiderable difficulties of correcting the data. In general, this involved examining each of the 1350 observations (farms), and checking for inconsistencies among the 505 variables. This was possible because of the disaggregated nature of the data set.

Section III deals with the stratification of the data set into ecological zones, i.e., regions within which climatic and soil conditions can be roughly assumed to be constant. All farms within each ecological zone, then, can grow the same variety of crops, and have the same available technology.

A more detailed analysis of the variables obtained from the Small Farm Sample Costs Survey is found in Section IV. There we will describe the actual variables for which we have information, the way in which these variables differ from the variables specified in the model, the relative credence we can put in the data as coded, and what effects this misspecification is likely to have on our parameter estimates.

The last section performs a similar function with the aggregate time series data which we shall use. In other words, Section V describes the source and scope of the data, the deviation of the given data set from the specification of the model, and the manner in which this misspecification is to be dealt with.

I. THE SMALL FARM SAMPLE COST SURVEY

The basic set of data to be used in estimating farm production functions in Kenya, is the Small Farm Sample Costs Survey, 1969-70, conducted by the Statistics Division of the Ministry of Finance and Economic Planning of the Republic of Kenya. Kenya is divided administratively into provinces, districts, divisions, locations, and sub-locations, the last of these corresponding roughly to the areas of local government under the aegis of tribal authorities, the sub-chiefs. Of the forty districts of Kenya, which correspond roughly to tribal areas, twenty-one (all of Nyanza, Western, and Central Provinces, the Rift Valley districts of Nakuru, Nandi, and Kericho, all of Eastern

Province except Kitui, Isiolo, and Marsabit Districts, and the Coastal Districts of Taita and Kilifi) can be said to contain some 90 percent of African farms.[1] Seventeen of these districts were included in the Sample Costs Survey of 1969-70. Within each district certain sub-locations were chosen in order to ensure that there were the requisite number of observations on each of the enterprises (crops) which were to be studied--improved and unimproved dairy, local maize, hybrid maize, coffee, cotton, pyrethrum, and tea. Within each sub-location farms were chosen at random from the list of registered farms (probably an unrepresentative sample). Thus the procedure was one of stratified random sampling, although it is not clear that the set of farms from which the sample was drawn contained the universe of all farms within each stratum (cf. map on following page for distribution of sample).

Each interviewer was given a questionnaire which contained over three thousand entries. Certain entries, such as capital stock estimates, inventories, livestock numbers, etc., were to be filled out at the beginning and end of the survey period--April 1, 1969 and March 31, 1970, respectively. Others, such as inputs of labor, fertilizer, insecticide were to be filled out on a monthly basis. Interviewers were instructed to ask questions such as "How much time did you and your family spend weeding maize this month?" From a whole set of such questions the interviewer could estimate the total monthly inputs of of labor into maize.

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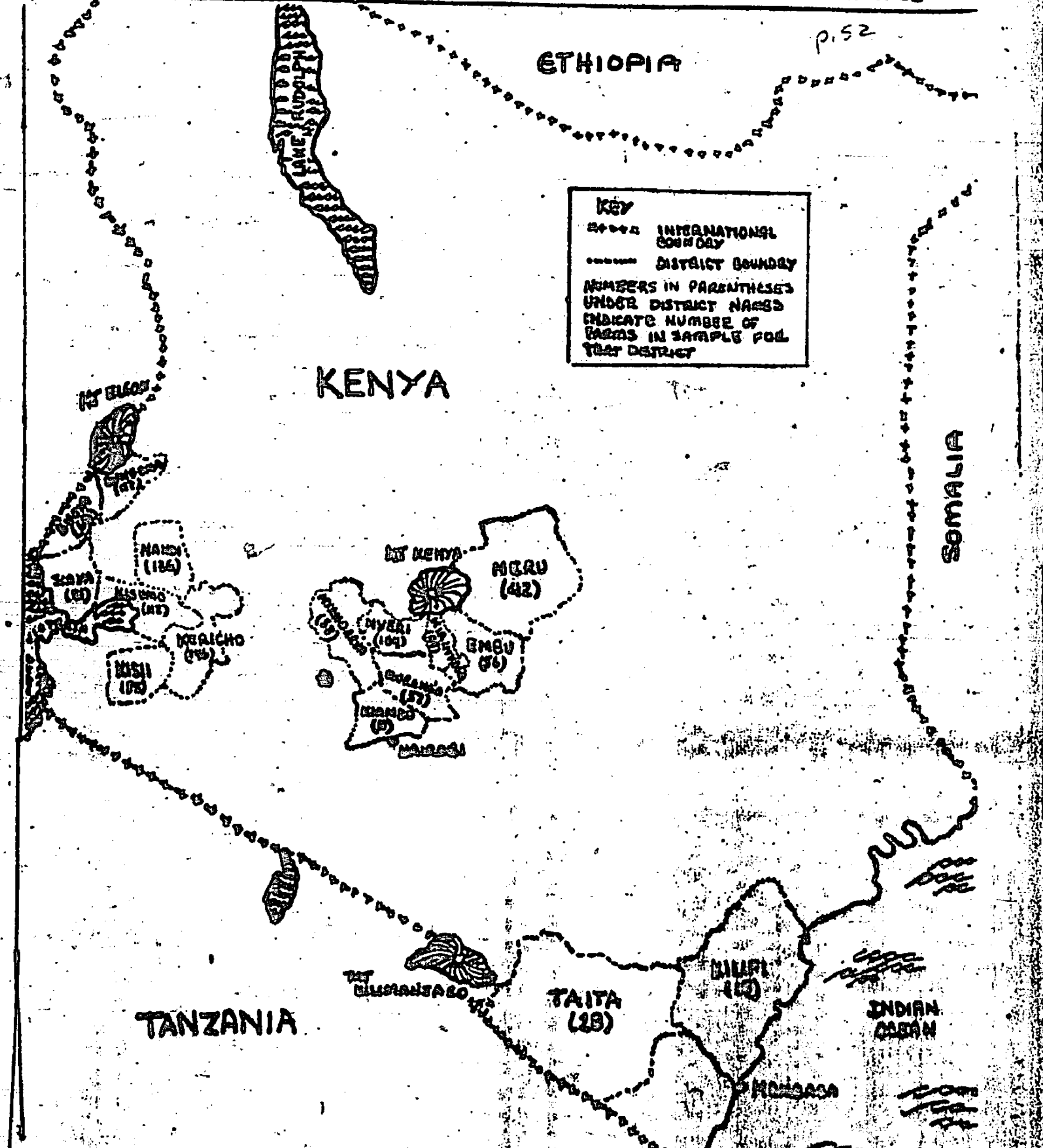
[1]All of the small-holder tea, 99 percent of the small-holder coffee, all of the cotton, and about 75 percent of the pyrethrum are grown in these areas.

DISTRIBUTION OF SAMPLE

p.52



At the end of the year, the information on the questionnaire was coded into 505 variables per farm and put on magnetic tape. Thus for each farm, information was obtained on the quantities of all inputs used, all output produced, the cash value of those outputs, the distribution of outputs between home use and market, capital stock at the beginning and end of each survey period, debt obligations, and some socio-economic data such as education, age, etc.

II. EDITING THE DATA

The difficulties involved in determining to what extent the final figures recorded for posterity on magnetic tape relate to the "true" values are enormous. The problems of survey research are large enough in a developed country; in a less developed country, where farmers keep few or no records, where there is distrust of interviewers, where procedures for supervision are somewhat haphazard, one is tempted to throw up one's hands in despair. There are so many places where the information could be incorrect--the farmer's recollection could be faulty, he could lie to the interviewers, the interviewer could be lax or dishonest, the coding could be incorrect, or even the punching of data on to cards could be faulty. And yet with all these possibilities of error, we shall see that we do achieve surprisingly good results.

Setting aside the indeterminate question of measurement error for the moment, the Small Farm Sample Costs Survey comprises a gold mine of information for the researcher--a sample of 1350 farms throughout the country, with information on all inputs, outputs, and prices. We believe there is no similar store of information available for any other less developed country, on a nation-wide basis.

As noted above, as the information passed on its way from farm to magnetic tape, there are many possible points at which the received data set could diverge from "truth." Since I had no control over the collection process, it was necessary for me to develop objective tests by which the data could be evaluated and corrected. Since the data were in such a disaggregated form, it became possible to pose a series of consistency tests by which the most egregious errors could be eliminated. There are three distinct categories into which these errors can be divided:

Domain Error. If any variable had a value exceeding 9999, a check was made to see if the information was not mispunched. That is, punching information in the wrong columns could lead to results that were clearly out of bounds, such as 70000 man-days of labor used in producing coffee. This was relatively easy to correct, as only capital values and land values were generally in five figures.

Consistency Error. Production requires at least some form of labor and land inputs. Thus if there were some positive output of cotton there had to be at least some type of labor input as well as land input. Often, once detected, the errors were easy to correct. A series of inputs into hybrid maize, with no output, occurring in the same farm as a positive value for local maize output with no local maize inputs was interpretated as implying the mispunching or miscoding of the output variable, and the value for hybrid output was assumed to be in reality the value coded for local maize output, and the latter was corrected to zero.

Where there was but one error (a missing labor input or a missing land input or a missing output value) and a corresponding error in another enterprise, the correction procedure was straightforward. Where there was more than one error, the observation was generally dropped from the sample. It was also assumed that for permanent crops (tea, coffee, and pyrethrum) land inputs during the long rains had to be equal to the land inputs during the short rains (cf. p. 60). Where this was not true, the sum of all land inputs was checked to see if it equalled the total land area as coded.

Sum Errors. In numerous categories, both the total values and the components of that total were entered. For example, the total capital value of the farm at the beginning and end of the period was entered as well as the specific categories--land, buildings, and tools. If the total did not equal the sum of the parts, then that set of variables was checked, first for inconsistencies that might have been caused by mispunching, and then, if it seemed reasonable, the total was changed rather than any individual part. For example, if the sum of all purchased inputs into tea equalled 497 sh., and the various components were 400 sh., 900 sh., and 7 sh. (a sum of 1307 sh.), it is logical to assume that the variable value of 900 sh. was in reality 90 sh., and had been punched in the wrong column.

All in all there were eighty-three such tests, and 1324 correctable errors. One hundred and eighty-four farms had to be dropped from the sample because there was no clear-cut way of dealing with the errors. It was then decided that even though the resulting information was consistent, certain locations revealed a pattern of information that was patently incorrect. This was especially related to labor inputs. There were certain sub-locations where labor inputs seemed to be largely understated. These areas were excluded from the main body of the sample on the basis of whether the average labor/land ratio was less than twenty man-days per acre.

III. SAMPLE STRATIFICATION

The vast climatic range of Kenya has already been discussed in Chapter II. It was decided to divide the sample of included farms into ecological zones within which climatic conditions are roughly similar. The ecological mapping of Kenya has not yet been carried out in great detail, but several criteria have been suggested, dating back to the colonial period of the 1950's. The scheme which will be used here is based on the ecological divisions found in Clayton, which are enumerated in Table IV-1 below.

TABLE IV-1

ECOLOGICAL ZONES IN KENYA--CRITERIA BY PROVINCE

Ec. Zone		Altitude Range (thousands of feet)			
		Nyanza & Western	Rift Valley	Central & Eastern	Coast
3.	Balanced Mixed Farming	5-7	7-9	6.5-7.5	--
4.	Kikuyu Grass	---	---	5.5-6.5	over 5.5
5.	Star Grass	4-5	---	4.5-5.5	4.0-5.5
6.	Grass Plains, Savannah, Coastal Belt	2-4	3-7	3--4.5	0-4

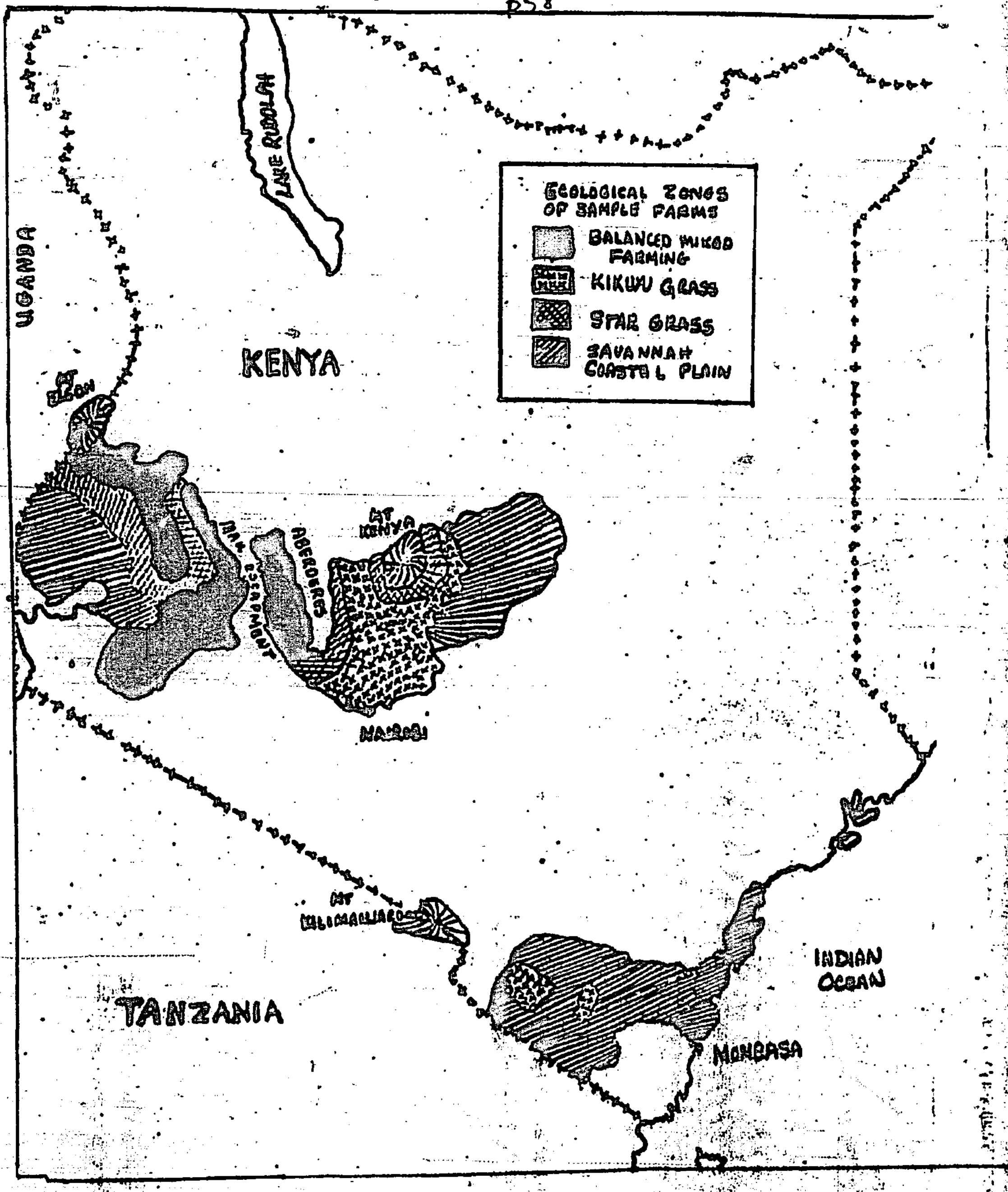
Source: E. S. Clayton, Agrarian Development in Peasant Economies (Oxford: Pergamon Press, 1964), p. 36.

Ecological Zone three includes some of the finest arable land in Kenya, suitable for tea, pyrethrum, coffee, maize, and dairy. Most of the land in this zone is located in the Western Highlands around Kisii, and across the Great Rift Valley. Zones Four and Five occur most often in the Central Highlands on the slopes of Mt. Kenya and the Abederes Range. The Kikuyu Grass Zone, which is at a higher altitude and consequently gets more rain, is suitable for coffee and tea, as well as the subsistance crops of maize and dairy. However, these mountainous areas are not nearly as suitable for large-scale farming as in Zone Three, due to the uneven terrain. The Star Grass Zone is a coffee-growing region. Zone Six is a conglomerate, including the low-lying areas of the Lake Victoria littoral, and the coastal belt, an area of mostly subsistance farming with some coffee and cotton. These are among the poorest agricultural areas in Kenya.

IV. THE CROSS-SECTIONAL DATA SET

Outputs. All outputs are in physical terms--bags of maize, gallons of milk, pounds of coffee, etc. These measures are probably close to the actual values, since records exist for those crops which are marketed, and maize in store could be measured directly by the interviewer.

Labor Input. Labor inputs, both hired and family, are measured in man-days of eight hours each. An eight hour labor input of a man or woman was counted as one man-day, while an eight hour input of a child (under sixteen) was counted as one-half a man-day. Unfortunately, no information was coded concerning the time path of labor inputs, and this makes it more difficult to answer the important questions of the employment p58 ECOLOGICAL ZONES



generating possibilities of increased agricultural production. Among the variables coded, was a general labor input. However, it seemed that different interviewers had different ideas as to what should be considered general labor, some allocating such chores as land clearing, repairing of tools, etc. to individual crops, while others were more discriminating. In order to resolve this difficulty, it was decided to allocate the general labor proportionately among the various crops. Of all the variables coded, the labor figure is probably the least reliable.

Purchased Inputs. All non-durable purchased inputs were aggregated together and shilling values were used. This raises all the familiar problems of the use of value measures rather than physical ones [cf. Nerlove, 1965]. This problem is compounded by the differing degrees of monopoly power that exist in different areas associated with the selling of such factors as fertilizer and insecticides. Nevertheless, no viable alternative to value measures seemed available.

Land Inputs. Land is measured in physical units (acres) for each crop. Within each ecological zone no attempt was made, as no information existed, to differentiate land on the basis of quality. Moreover, as cropping patterns varied from region to region (most regions have two planting seasons, a short rainy season and a long rainy season), some common land variable had to be computed. For permanent crops (tea, coffee, and pyrethrum), no difficulty arose since the same land was kept under these crops all year round. For temporary crops (maize, cotton, and dairy), it seemed that they were planted either during the long rains or the short rains, rarely during both. This suggested that each of the following patterns should be coded as a land input of one acre:

Long Rains	Short Rains
1.0	1.0
1.0	0.0
0.0	1.0
0.5	1.5

All land not planted with crops was considered to be grazing land. This was divided between grade and native cattle on the basis of the proportion of total livestock accounted for by grade and native cattle respectively.

Capital. Opening and closing value measures were coded for tools, buildings, dairy deadstock, grade cattle, unimproved cattle, other livestock, and inventories. As Yostopolus noted, stock variables are very poor measures of capital services, even when depreciated. The most important capital inputs into small scale agriculture are livestock and tree inputs where the vintage of capital becomes very important. Value has been used as a measure of livestock inputs as it is more closely related to the vintage structure of cattle than mere numbers. There are no data on the number or vintage of tree crops, but as Kenya is party to the International Coffee Agreement, no legal new plantings of coffee have occurred since 1964. Thus all coffee trees are over five years old, the data of maturation. There's no marked deteriorations of doffee trees for at least the first forty years of planting. Tea inputs were divided between tea in production (over five years) and immature tea. Only the inputs into the former were considered, the latter being included under the category of investment. Pyrethrum has a three-year life cycle; it is thus necessary to assume that all farmers have divided their pyrethrum acreage equally among the three vintages of pyrethrum, thus keeping a constant ratio of services to stock across all farms.

Prices. All prices are farm-gate, net of transportation costs. Wages include that portion paid in kind. For farms that did not enter one or another of the product or factor markets, average prices for the sub-location were used.

V. TIME SERIES DATA

Before actually discussing the time series data which we will use, it might be well to recapitulate the process by which we intend to obtain the variance-covariance risk matrix. Ideally, we would like to have a time-series of farm level data, from which we would calculate the actual random disturbances in output over time. Unfortunately, the only data which are available, are district-level aggregate time series of marketed output and price to the producer.

These aggregate data differ from the microeconomic data we require in two ways: (1) they aggregate disturbances over an entire district (which may include more than one ecological zone), and (2) more importantly, they incorporate changes in output that may be due to causes other than random disturbances. These include for example, changes in input quantities and changes in technology. What we will attempt to do, then, is to extract from these aggregate series the systematic portion, due to changes in economic variables, or to secular or cyclic trends, thus leaving the random component, from which we will calculate our estimates of the variance-covariance matrix.

The data to be used in estimating the variance-covariance matrix were collected from various ministries and marketing boards, as well as from published data. Basically, the output series consists of twelve year time series of marketed output for small farms, at the district level. This is also true for the price series. For maize, coffee, and tea, data were available by district, whereas for pyrethrum, cotton, and milk, only aggregate data for all of Kenya were available. Of the three price series (tea, coffee, and pyrethrum), it was possible to get district level information only for tea. These series can be found in Appendix I.

The next chapter, after a brief discussion of estimation procedures, is devoted to using these two sets of data (cross-section and time series) to estimate the production functions for each of the enterprises studied, and the variance-covariance matrix of risk for each district.

CHAPTER V

EMPIRICAL RESULTS

In this chapter we shall present the results of the empirical part of this study--the estimates of the parameters of the production functions and of the exogenous variables, the variance-covariance matrix of the random disturbances. Before presenting our results, we shall have need in this chapter to explain our estimation techniques, and justify our choice of functional form.

In Section I we discuss the Marshak-Andrews objections to Ordinary Least Squares estimates of production functions, and conclude, that in the context of agricultural production in Kenya, these objections do, indeed, have validity. Consequently, we shall use instrumental variables as the procedure for estimating the parameters of the production functions, using as instruments the exogenous variables (capital stock, prices, total factor constraints, etc.) discussed in Chapter III.

The second section deals with the choice of functional form for the production functions. Neoclassical theory suggests certain properties which we would like production functions to exhibit, and Cobb-Douglas production functions fulfill this set of constraints. In addition the Cobb-Douglas specification does not appreciably decrease the degrees of freedom, provides ease of estimation, and has been the subject of a copious literature relating to the problems of estimation.

In Section III we provide the estimates of the parameters of seventeen Cobb-Douglas production functions (eight enterprises across four ecological zones, although not all crops are present in each zone), and discuss the properties of the production processes suggested by these estimates. We next proceed to the estimation of the variance-covariance matrix. Section IV deals with the technique which we shall use in the estimation process, while Section V concludes the study by presenting the results of this estimation on a district by district basis.

I. PRODUCTION FUNCTIONS--THE ESTIMATION PROCEDURE

Marschak and Andrews, in a seminal paper published in 1944, demonstrated that cross-sectional ordinary least squares estimates of Cobb-Douglas production functions were both biased and inconsistent because they failed to take account of the fixed factors (management) specific to each firm which influenced the process of choosing the firm's input mix. Since these omitted factors were included in the residual, and since they were correlated with the independent variables, one of the basic assumptions that guarantees that ordinary least squares estimators are best linear unbiased estimators has been violated [Johnston]. The conclusions drawn by Marschak and Andrews, and by later investigators such as Nerlove [1965] and Walters [1963], are that production function estimation requires some technique that takes into account the simultaneity of the system. In other words, one really wishes to estimate a complete system of profit (utility) maximization equations such as those presented in Chapter III (equation 3.15, p. 42).

Since (1) Ordinary Least Squares estimators would be biased and inconsistant, and (2) parts of the system are non-linear, the technique which we have chosen to use in estimating the agricultural production functions of this study is that of instrumental variables. We have noted before that prices, capital stock, specific capital inputs such as coffee trees, total land and labor availability, all were exogenous variables within our time frame, and varied widely across farms. Consequently we had available a reasonably large set of exogenous variables which could be used as instruments. In addition to the variables listed above, additional instruments could be found in the educational level of the farmer and dummy variables related to the location of the farm.[1]

II. THE CHOICE OF A FUNCTIONAL FORM

Choosing a functional form for the production function presented something of a problem. Having no priors on how hoeing and nitrogen phosphate combined to produce a bag of maize, it became necessary to choose a specification of the production function which was easy to handle, estimable in terms of the data available, and consonant with certain assumptions derived from neoclassical theory. Among these assumptions are: (1) marginal products should be positive; (2) the

[1] In our model, the variance-covariance matrix provides a whole set of exogenous variables. However, we have only observations on a district basis, i.e., within a district all the elements of this matrix are equal across farms. We are estimating production functions within an ecological zone, and there are generally several districts within a given ecological zone; thus, the district within which the farm is located is a proxy variable for the variance-covariance matrix.

marginal product of any input should decrease as the level of that input is increased while other inputs are held constant; and (3) there should be no a priori restrictions on returns to scale [Allen, Brown].

A digression on returns to scale: intuitively, one expects production to be a constant returns to scale process. One would expect, that if one took the same farm, and somehow cloned it, the output of the two farms together would be exactly double that of the original farm. Accordingly, one develops "stories" about increasing or decreasing returns to scale--the former due to indivisibilities of some input (donkeys or tractors); the latter, to the omission of some constant input when all other inputs are expanded (management or land quality, for example). In those terms, then, constant returns to scale is a method for testing the specification of the production function, and decreasing returns to scale suggests the omission of an important factor of production. This does not mean that we shall stipulate that our production functions exhibit constant returns to scale; rather we shall have more faith in our estimates if the sum of the estimated elasticities is close to unity.

The Cobb-Douglas functional form seems to fit all of the conditions enumerated above [Cobb and Douglas]. In addition, there is a copious literature dealing with the estimation problems encountered in using Cobb-Douglas production functions, and this literature will aid us in our analysis of the properties of the estimators. Many of the same properties also hold for other production functions [e.g., the Constant Elasticity of Substitution production functions, the family which includes the Cobb-Douglas as a special case], but these production functions would be difficult to estimate given our model and the available data [Arrow, et al.]. For all the above reasons we have chosen the Cobb-Douglas as the functional form which we shall use in estimating our production functions.[2]

The inputs into these Cobb-Douglass production functions can be divided into five categories--land, family labor, hired labor, purchased inputs, and capital stock. Because of the problem of zero-levels for some inputs for some crops, most estimations will actually use a subset of these inputs. In particular, not all crops will have inputs of hired labor or fixed capital, for example. While there are a number of ways of handling the problem of zero-level inputs into Cobb-Douglas production functions, all of these lead to biased estimators [Johnson and Rausser]. Fortunately for us, for each individual production function, those inputs which had zero-levels for some farms,

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[2] Rasmussen, in a study of farm accounts in Denmark, offers the following justification for the use of Cobb-Douglas production functions:

> Most studies in this field have used the Cobb-Douglas production function, partly because it is so easy to use, partly after an argument that so few degrees of freedom are lost by this function, but without doubt mainly due to the experience that this function fits the data very well. When one can readily obtain a multiple correlation coefficient as high as 0.97 to 0.99 and at the same time a distribution of actual products around the regression surfaces which is a near approximation to a normal distribution, there can hardly be much wrong with this type of function as a working hypothesis...
>
> In future some worker may find a function which is more appropriate to the study of farm production functions, but at present it would seem that there is little need to discard the Cobb-Douglas function in spite of some workers' disinclination to accept the constant elasticities and linear least-cost-combinations implied [Rasmussen, pp. 63-64].

never were of any great importance in other farms, and thus the elimination of the input from the specification of the production function seemed a reasonable procedure.

III. PRODUCTION FUNCTION ESTIMATES

In this section we will present the estimates of the Cobb-Douglas production functions for the eight enterprises for which we have data. We will present these instrumental variables estimates by crop across ecological zones.

Maize. Local varieties of maize are the most widely grown crops in Kenya, and are produced on 341 of the 410 farms in our sample. In the balanced ecological zone (Zone 3) maize tends to be grown on a larger scale, and the bulk of it is marketed, while in the other zones, less suitable for large-scale, mechanized agriculture, maize is grown basically for consumption purposes, with only the surplus marketed. The results are shown in Table V-1.

As can be seen from the Table, Zones 3 and 5 seem to have similar production functions as do Zones 4 and 6. This is due to the fact that in both of the latter zones the scale of production is much more limited, and the average labor land ratio is much higher (153 man-days/acre for Zones 4 and 6, as opposed to 73 man-days/acre for Zones 3 and 5). Thus in Zones 4 and 6 farmers tend to use more labor-intensive techniques, while in the other two zones, land-intensive techniques predominate. Tools and purchased inputs tend to have similar production elasticities across ecological zones, except in the balanced

TABLE V-1

PRODUCTION FUNCTIONS FOR LOCAL MAIZE

	Zone 3	Zone 4	Zone 5	Zone 6
Land	.732840* (5.56845)	.061345 (.415594)	.524968* (3.62005)	.145665 (1.55819)
Family Labor	.153251 (0.970143)	.283874* (2.15550)	.087206 (0.642976)	.357218* (2.15163)
Hired Labor	.161816 (1.42334)	.135488 (1.83327)	.023418 (0.38966)	.144315 (1.55109)
Purchased Inputs	.002335 (0.04456)	.282994* (1.83674)	.139455 (1.10802)	.145029 (1.422102)
Tools	.071180 (1.33813)	.051447 (0.57123)	.053931* (2.46481)	.053582* (1.73054)
Constant	1.05758	-.286782	-0.034268	-1.05133
Returns to Scale	1.118017	.815058	.828978	.845089
R^2	.7087	.1684	.2968	.3846
Number of Farms	78	76	109	78

Note: As in all the tables which are to follow, the numbers in parentheses represent the T-statistic for each parameter estimate. Starred estimates are significant at the 5 percent confidence level.

ecological zone (Zone 3) where few farms used purchased inputs, and the elasticity of purchased inputs was essentially zero.

Hybrid Maize. Hybrid maize is rapidly being introduced into Kenyan agriculture, although it seems to be currently limited to the larger-scale small farms, which produce maize as a cash crop (this seems to provide more evidence of our conclusion that risky innovations are more likely to be undertaken by wealthier farmers, i.e., decreasing absolute risk aversion). The most important difference between hybrid and local maize productions, is the high elasticity of purchased inputs in the production of the former. Hybrid production demands more sophisticated production techniques, including the use of fertilizers and insecticides. This is another reason for the limiting of hybrid maize production to larger farms, since these wealthier farmers are better able to provide the case outlays required in hybrid maize production. The estimated production functions for hybrid maize can be found in Table V-2.

Coffee. Coffee is the most important cash crop in Kenya; 132 of our 410 farms are engaged in coffee production, with the coffee-growing farms spilt almost equally among ecological zones 3, 4, and 5. The coffee production function results are shown in Table V-3. The results for ecological zone 3 are rather disappointing with very low R^2 and with returns to scale of less than 0.6. Clearly, there are some problems with these estimates. Moreover, the elasticity of output with respect to land is very low in Zone 3, as compared to the output elasticities of land in both types of maize production. In the other two zones, the importance of labor was clearly emphasized by the high

TABLE V-2

HYBRID MAIZE PRODUCTION FUNCTIONS

	Zone 3	Zone 5
Land	.323676*	.145590
	(4.55124)	(0.435503)
Family Labor	.064170	.171323
	(0.377956)	(0.960717)
Purchased Inputs	.275551*	.225316*
	(3.211071)	(1.855091)
Tools	.032048	.151515
	(0.462712)	(1.26402)
Constant	1.56859	0.691953
Returns to Scale	0.695535	0.693744
R^2	.6834	.3531
Number of Farms	71	16

TABLE V-3

COFFEE PRODUCTION FUNCTIONS

	Zone 3	Zone 4	Zone 5
Land	.160799	.177201	.377972
	(1.40099)	(0.777269)	(0.97351)
Family Labor	.336366*	.472213*	.37003
	(3.46771)	(3.03342)	(0.99959)
Hired Labor	.060415*	.172213*	.339035*
	(1.77124)	(2.44611)	(2.30585)
Purchased Inputs	.000355	.247332*	.11703
	(0.05575)	(3.91021)	(0.490873)
Constant	4.55845	3.82124	3.87714
Returns to Scale	.55758	1.068850	1.204043
R^2	.3323	.4735	.2908
Number of Farms	38	50	44

elasticities. Purchased inputs were also of some importance, while capital had essentially zero elasticities and was not used in our final specification. This is not surprising in that the trees were already planted, and little use could be found for tools. This will turn out to be true for all tree crops.

Tea-Pyrethrum-Cotton. The other important crops in our sample are tea, pyrethrum, and cotton, all of which are limited to specific areas of the country. Smallholder tea is grown on the upper slopes of Mt. Kenya and in the Kisii Highlands (ecological zone 4); pyrethrum is also grown in highland areas, but mostly in the Rift Valley and on the Mau Escarpment (ecological zone 3); cotton is grown in lower elevations along the coast and Lake Victoria (ecological zone 5). The estimated production functions for these three crops can be found in Table V-4.

TABLE V-4

TEA, PYRETHRUM, AND COTTON PRODUCTION FUNCTIONS

	Tea (Zone 4)	Pyrethrum (Zone 3)	Cotton (Zone 5)
Land	.689502* (3.72855)	.255185 (0.874094)	.399953* (2.71032)
Family Labor	.316404 (1.35835)	.336758* (1.96214)	.484360* (10.4310)
Hired Labor	---	.4444148* (2.82997)	---
Constant	8.19049	3.15198	3.33881
Returns to Scale	1.005906	1.036091	.872763
R^2	.6835	.1939	.9139
Number of Farms	16	45	16

Pyrethrum seems to exhibit a production pattern similar to coffee, in that there are high elasticities for labor. Tea, on the other hand has high elasticities of output with respect to land (not surprising since the land variable includes the large capital input involved in planting tea shrubs and allowing them to grow--a five year germination period). Cotton also seems to be a labor intensive crop. The remarkable thing is that none of these cash crops seem to require large inputs of fertilizers or capital and thus, they are extremely appropriate cash alternatives for small-scale farmers in Kenya, in areas where climate permits their production.

Dairy Products. There are two types of dairy production in Kenya--the first using native breads of cattle we shall call unimproved; the second using imported breads (perhaps cross-bred with native stock for heartiness), which we shall call improved dairy. In our sample there were 100 farms using improved breeds, while 158 were still using native cattle. The former, while much more productive, require many more inputs of a modern type--feeds, dips, and the like--and purchased inputs would be expected to have higher elasticities than those of unimproved cattle. Dairy production is a very land-intensive process, and for the most part herding and milking are left to the children. One would expect very low elasticities of land and labor for these two enterprises. One would also expect higher marginal value products for cattle in the case of improved vs. unimproved cattle. As can be seen from the results (Table V-5 for unimproved dairy production and Table V-6 for improved dairy production) our expectations have been born out.

TABLE V-5

UNIMPROVED DAIRY PRODUCTION

	Zone 3	Zone 5	Zone 6
Land	.215596 (1.06080)	.294103 (0.735521)	.497142* (2.57955)
Family Labor	.309918 (0.662194)	.142911 (0.465573)	.073145 (0.397572)
Purchased Inputs	.038969 (0.366116)	.169691* (1.75813)	.0060650 (0.527352)
Cattle	.619764* (2.79197)	.270706* (1.91394)	.239004* (1.80760)
Constant	-2.40420	2.18407	1.50352
Returns to Scale	1.18429	.877410	.869950
R^2	.5492	.1680	.1679
Number of Farms	37	52	69

TABLE V-6

IMPROVED DAIRY PRODUCTION FUNCTIONS

	Zone 3	Zone 4
Land	.007227 (0.45523)	.172214 (1.45513)
Family Labor	.064303 (0.710991)	.096661 (0.988108)
Hired Labor	.069859 (1.134418)	----
Purchased Inputs	.315585* (3.450011)	.292241* (1.88744)
Cattle	.440332* (2.00933)	.386211* (1.88112)
Constant	1.22826	1.45022
Returns to Scale	.90529	.98267
R^2	.4265	.3502
Number of Farms	77	23

A fuller discussion of the implication of these estimates must await the next chapter.

IV. THE VARIANCE-COVARIANCE MATRIX: ESTIMATING TECHNIQUE

The decision model presented in Chapter III assumes that the farmer has approximate knowledge of the moments of the distribution of the random variables that effect his economic well-being, the random components of output and price which we have denoted as γ_i and δ_i respectively, $i = 1, 2, \ldots, K$. This is a case of empirical approximate risk [Manges]. This knowledge presumably comes from observation of these variables over a period of time. For example, each farmer has knowledge of his outputs and inputs into local maize over the last twelve years. That is, he has observed:

$$Q_{mt}, L_{mt}, A_{mt}, H_{mt}, X_{mt}, K_{mt} \quad \text{for } t=1, 2, \ldots, 12$$

where

Q_{mt} = Output of maize at time t

L_{mt} = Family Labor input into Maize at time t

A_{mt} = Land Inputs into Maize at time t

H_{mt} = Hired Labor Inputs into Maize at time t

X_{mt} = Purchased Inputs into Maize at time t

K_{mt} = Capital Inputs into Maize at time t

Since in a time series study of production functions the Marschak-Andrews description of the economic content of the residual has less force (cf. Section I), it is appropriate to take least-squares regressions of the following forms:

$$(5.1) \quad Q_{mt} = C_m L_{mt}^{\alpha_1} A_{mt}^{\alpha_2} H_{mt}^{\alpha_3} X_{mt}^{\alpha_4} K_t^{\alpha_5} \gamma_{mt}$$

One can then calculate the residuals, $\gamma_{mt} = Q_{mt}/\hat{Q}_{mt}$, and have twelve point observations of the distribution of the disturbance term. From these observations we can get estimates of the variance-covariance matrix. These variances and covariances of output are the moments that the farmers use in making their decisions.

Similarly, with respect to the random component of prices, the farmers have observed a time series of prices for each crop; in the case of coffee this would be:

$$P_{cft} \quad t = 1, 2, \ldots, 12$$

There are many models describing the way the farmer deals with this information, the most commonly used of which is the adjustment expectation model of Nerlove [Nerlove, 1958]. We will use a variation of the Nerlove model in our estimation of the disturbances affecting prices.

If the farmer does indeed behave in such a manner in trying to quantify the effects of uncertainty on his income, this does not immediately provide us with information enabling us to imitate the farmer. If we had the same information as the farmer, we could perform the same statistical tests. Unfortunately we have no time series data on farm level inputs, outputs, and prices. What we do have, as we noted in Chapter IV, are district level data on marketed output and price to the producer. Our general procedure will be to attempt to extract the systematic portion from each of these series, that is the changes in output levels due to changes in prices, changed input usage, new technologies, new wage employment opportunities, etc. If we can do this we will be left with the set of observations on the disturbance term, from which we can calculate the variance-covariance matrix.

<u>Output Disturbances</u>. In this model we are assuming the following:

(1) Within a district the disturbances affecting farm-level output are identical;

(2) these disturbances affect output multiplicatively;

and thus,

(3) the disturbance, γ_i, which affects the marketed output of the <u>ith</u> crop, at the district level, is identical to the disturbance, γ_i, which affects output at the level of the individual farm.

Since the disturbances are multiplicative, it makes sense to use a semi-logarithmic model of the following form:

$$(5.2) \quad q_i = Q + bt + c\ln P_i + \gamma_i$$

where q_i = the natural logarithm of marketed output of the <u>ith</u> crop

t = time

P_i = Price of the <u>ith</u> commodity

γ_i = The random fluctuation of output of the <u>ith</u> crop

Then, $\gamma_i = q_i - \hat{q}_i$

There is one problem with such a procedure. The series we have, make no distinction between hybrid and local maize production, or between improved and unimproved dairy production. In order to determine the riskiness of these enterprises vis-à-vis each other we will take refuge in our model. If the marginal products of labor into hybrid maize is twice that of labor into local maize, then our theoretical model says that production of hybrid has twice the marginal increment to risk as does production of local maize. It is not a simple matter to go from this fact to the relative values of the variances of the disturbances effecting local maize and hybrid maize respectively, (cf. equation 3.16, p. 43); we shall make the rather heroic assumption, (probably accurate enough) that the ratio of the variances equals the ratio of the marginal products. The regression results for the equations such as (5.2) can be found in Appendix II.

Prices. Deriving the variance-covariance matrix of the disturbances affecting prices is somewhat simpler than deriving that affecting output. This is because district level price-series should not differ very greatly from farm-gate prices. Using a Nerlovian adjustment model the regression equations which we shall estimate are of the following form:

$$(5.3) \quad p_{it} = f(p_{it-1}, t) + \delta_t$$

where

p_{it} = natural logarithm of the price of the ith commodity

t = time

δ_t = random disturbance affecting the ith price.

As with output, δ_t is equally calculated $(p_{it} - \hat{p}_{it})$, and from these point estimates, the variance-covariance matrix of the joint distribution of $\delta_1, \delta_2, \ldots, \delta_n$. Since we have assumed that γ_i and δ_i are independent, the following equation holds:

$$(5.4) \quad \sigma_{ij} = \text{cov}\gamma_i\gamma_j + \text{cov}\delta_i\delta_j + \text{cov}\gamma_i\gamma_j\text{cov}\delta_i\delta_j$$

In the next section, we will provide our estimates of V, the variance-covariance matrix of the disturbances affecting the farmer's income.

V. THE VARIANCE-COVARIANCE MATRIX: RESULTS

The results of the estimation are presented in Tables V-7 to V-10. While the estimation was done on the district level (sixteen districts) there was more economic content in presenting the results by ecological zones, which have been the main sample strata we have been considering. There also seemed little point in presenting separate estimates for the disturbances affecting price and those affecting output, so these results consist of the σ_{ij}'s as represented by equation (5.4). The units are percentages (of expected income).

TABLE V-7

VARIANCE-COVARIANCE MATRIX FOR ECOLOGICAL ZONE THREE, BALANCED ECOLOGICAL ZONE
(Normalized deviation from mean expected income)

	Local Maize	Hybrid Maize	Coffee	Pyrethrum	Improved Dairy	Unimproved Dairy
Local Maize	0.285	0.382	-0.096	0.377	-0.150	-0.095
Hybrid Maize	0.382	0.552	-0.186	0.732	-0.293	-0.150
Coffee	-0.096	-0.186	0.442	-0.399	0.088	0.029
Pyrethrum	0.377	0.732	-0.399	1.345	-0.265	-0.088
Improved Dairy	-0.150	-0.293	0.088	-0.265	0.165	0.121
Unimproved Dairy	-0.095	-0.150	0.029	-0.088	0.121	0.080

TABLE V-8

VARIANCE-COVERIANCE MATRIX FOR ECOLOGICAL ZONE FOUR, KIKUYU GRASS ECOLOGICAL ZONE
(Normalized deviation from mean expected income)

	Local Maize	Coffee	Tea	Improved Dairy
Local Maize	0.924	0.065	0.799	0.074
Coffee	0.065	0.526	-0.303	0.032
Tea	0.799	-0.303	0.591	-0.171
Improved Dairy	0.074	0.032	-0.171	0.165

TABLE V-9

VARIANCE COVARIANCE MATRIX FOR ECOLOGICAL ZONE FIVE, STAR GRASS ECOLOGICAL ZONE
(Normalized deviations from mean expected income)

	Local Maize	Hybrid Maize	Cotton	Coffee	Unimproved Dairy
Local Maize	0.507	0.619	-0.022	0.012	0.046
Hybrid Maize	0.619	0.734	-0.035	0.019	0.073
Cotton	-0.022	-0.035	0.419	0.030	-0.145
Coffee	0.012	0.019	0.030	0.120	-0.005
Unimproved Dairy	0.046	0.073	-0.145	-0.005	0.080

TABLE V-10

VARIANCE-COVARIANCE MATRIX FOR ECOLOGICAL ZONE SIX,
MIXED ECOLOGICAL ZONE
(Normalized deviations from mean expected income)

	Local Maize	Unimproved Dairy
Local Maize	0.132	0.115
Unimproved Dairy	0.115	0.080

These tables point out many interesting facts. First, we should note the large values for the variances of income from any crop (the elements of the main diagonal) thus justifying once more our assertion that farming is a very risky business. For most crops it seems that gross income (price times marketed output) could vary by as much as 50 percent from year to year. Secondly, we should note the high levels and frequent negative signs of the covariances in these tables, a fact which suggests that there is considerable opportunity for reducing risk by producing more than one crop, as most Kenyan farmers do. Thirdly, we should note that those areas with greatest net income (zones three and four) also are areas with high variance of income, which implies that the bearing of risk must be compensated for by greater expected return. These suggestions raised by the variance-covariance estimates in the above tables, will be delved into more deeply in the next chapter, as we test our model, evaluate the marginal products implied in the production functions estimated in Section III, and discuss the relative riskiness involved in undertaking any particular agricultural enterprise.

CHAPTER VI

RATIONALITY AND ECONOMIC EFFICIENCY IN AN UNCERTAIN WORLD

The purpose of this chapter is to investigate the implications implicit in the estimations of the preceding chapter. In particular, we are interested in examining the following questions: (1) What is the relationship between the marginal value product of an input and its price? (2) Are the ratios of the marginal products of any pair of inputs equal in two alternative uses? (3) What is the relationship between the marginal value product of any input into a given crop and the marginal increment in risk of that same input? In each of the first three sections of this chapter we will examine one of these questions in order to determine if our model coincides with the Kenyan reality.

Section I is devoted to the examination of the marginal value products derived from the estimated production functions. More specifically, we will discuss the relationship between the marginal value product of an input and the input price. As was explained in Chapter III, we would not expect this relationship to be one of equality; however, if marginal value products are consistently greater than prices (which, as we shall see, is true in the case of several inputs), there must be some other extra-model considerations which are important.

In Sections II and III we will discuss the questions of economic efficiency. We will examine the two hypotheses put forward in Chapter III (pp. 42-43). The first, which will be the subject of Section II, is that economic efficiency implies that the ratio of the marginal products of any two inputs into any pair of crops should be equal. The second, which will be tested in Section III, is that the marginal value product of a given input into crop i will be greater than, equal to, or less than the marginal value product of that same input into crop j, as the marginal increment to risk of that input into crop i is greater than, equal to, or less than the marginal increment to risk of the input into crop j. We will conclude the chapter in Section IV by discussing the implication for the evaluation of farmer behavior of the results of these tests.

I. MARGINAL VALUE PRODUCTS AND INPUT PRICE

The marginal value products of each of the crops with respect to each of the inputs by ecological zone are presented in Table VI-1. We will analyze them in the following order:

(1) The relationship between marginal value produce and input price; and

(2) The marginal value product of any input across crops:

Land. In two of the ecological zones (Zone Three and Zone Four), marginal value products of land are clearly higher than any discounted value of land. This is probably because prices do not reflect the higher quality of this land (Zone Three, because it is a temperate area suitable for larger-scale, mechanized farming, and Zone Four, because its altitude permits production of the more profitable cash crops). In Zones Five and Six, the lower income areas, the price of land seems more in line with the average value of the marginal value products of land (cf. Table VI-2). There are several other explanations for these

TABLE VI-1

MARGINAL VALUE PRODUCTS BY ECOLOGICAL ZONES

A. Zone Three, Balanced Ecological Zone

	Local Maize	Hybrid Maize	Coffee	Pyrethrum	Improved Dairy	Unimproved Dairy
Land	157.95	218.73	15.55	63.59	93.10	77.27
Family Labor	0.85	0.56	0.26	4.95	0.59	0.27
Hired Labor	7.03	--	0.36	15.48	12.18	--
Purchased Inputs	1.44	3.27	--	--	3.45	0.28
Capital (Tools/cattle)	1.23	1.89	--	--	0.33	0.08

B. Zone Four, Kikuyu Grass Zone

	Local Maize	Coffee	Tea	Improved Dairy
Land	13.95	101.50	363.12	101.61
Family Labor	0.70	2.13	9.86	1.84
Hired Labor	1.87	1.47	--	--
Purchased Inputs	7.06	4.30	--	4.22
Capital (Tools/cattle)	1.13	--	--	0.60

C. Zone Five, Star Grass Zone

	Local Maize	Hybrid Maize	Cotton	Coffee	Unimproved Dairy
Land	39.28	86.09	92.38	110.78	33.64
Family Labor	0.66	1.04	0.43	0.84	0.26
Hired Labor	0.20	--	--	4.11	--
Purchased Inputs	1.07	2.78	--	1.37	0.88
Capital (Tools/cattle)	0.37	2.54	--	--	0.09

D. Zone Six, Mixed Ecological Zone

	Local Maize	Unimproved Dairy
Land	19.251	30.86
Family Labor	0.33	0.15
Hired Labor	3.86	--
Purchased Inputs	2.57	1.05
Capital (Tools/cattle)	0.60	0.48

TABLE VI-2

MEAN INPUT PRICES BY ECOLOGICAL ZONE

Ecological Zone	Net Income (shillings)	Price of Land (sh./acre)	Wage Rate (sh./man-day)
Zone Three	3479	515	3.50
Zone Four	2288	353	2.46
Zone Five	1257	498	1.58
Zone Six	1358	333	3.11

high marginal value products. First, most tree crops are limited in acreage by government licensing practices, or, as is the case in tea, by the fact that tea production on small farms is still in its infancy and is in disequilibrium. Secondly, land prices were calculated from average values within a sublocation, and no consideration was given to the amount of investment in the land. Thirdly, and probably most important, in a country where land markets are rudimentary at best, land prices must be accepted with some scepticism.

Labor. Except for the extremely profitable crops of pyrethrum in Zone three and tea in Zone four, both of which may be in disequilibrium, the mean marginal value products of family labor are extremely low. This is not surprising, for although Kenya is not a labor surplus economy in the same sense that many countries in Southeast Asia might be, there are few alternative opportunities for employment off the farm, and the opportunity cost of family labor throughout a crop year may be very low.

This presents something of a paradox, since hired labor clearly has a much higher marginal value product, and since there seem to be few land constraints (at least in some areas). Though some of this differential between hired and family labor may be due to quality differences, the bulk, I feel, lies in the problem of timing. Hired labor is used in seasons of great labor demand (planting and harvesting), and therefore has a much higher return. In fact, in many cases, the marginal value product of hired labor is greater that the wage rate.

Purchased Inputs and Capital. The marginal value product of purchased inputs is, in almost every case, higher than its price (since we've used value units for purchased inputs, the price is one shilling). This is also true for capital except in the case of unimproved breeds of dairy cattle.[1] In fact the returns to capital goods are extremely high (often on the order of ten times the value of capital services), and this suggests that one of the key bottlenecks to increasing agricultural production among small farms in Kenya is lack of credit availability. This would take two forms--short-term credit for the purchase of inputs used during the crop year (fertilizers, hired labor, dips, feeds, etc.), and longer-term credit for the purchase of capital goods (particularly improved breeds of dairy cattle). As we mentioned previously (Chapter II, pp. 28-29), credit in Kenya has been dispersed mainly for the purchasing of land, which while it has important redistribution effects, has a negligable impact on increasing agricultural incomes. We will return to this point later.

We have argued that one would not expect any clear relationship between the marginal value product of any input and its price. Nevertheless, only family labor seems to be used up to the point where the opportunity cost is equal to the price. Most other inputs seem to be under-utilized. This may be due to supply constraints caused by credit inavailability, or the shortage of hired labor during peak seasons. On the other hand, the underutilization of land may be due to (contrary to our specification) the limited substitutability among inputs.

[1]There is another explanation for the over-utilization of native cattle. Cattle plays a very important consumption role in prestige and traditions of East African peoples [cf. Ottenburg].

Marginal Value Products Across Crops. In Chapter III we derived the proposition that if farmers are risk averse, the marginal value products of any inputs across crops will not be equal, but will depend on the marginal increment to risk of each crop. This implies that the ranking of the marginal value products across crops will be identical for all inputs. While the data in Table VI-3 are not really appropriate for testing this proposition, they should provide us with some indication of whether or not our expectations are fulfilled.[2] That is, we should expect the ranking of coffee marginal value products to be the same for labor as it is for land.

These rankings are given in Table VI-3 below.

TABLE VI-3

RANKINGS OF MARGINAL VALUE PRODUCTS BY CROP, BY ECOLOGICAL ZONE

A. Zone Three, Balanced Ecological Zone

	Local Maize	Hybrid Maize	Coffee	Pyrethrum	Improved Dairy	Unimproved Dairy
Land	2	1	6	5	3	4
Family Labor	2	4	6	1	3	5
Hired Labor	4	-	6	1	2	-
Purchased Inputs	4	2	-	-	3	5
Capital	3	2	-	-	4	5
Coefficient of Variation	0.3	0.2	0.0	0.8	0.2	0.1

[2] The appropriate samples for testing this proposition are farms with identical cropping patterns. This is because risk is a property of a port-folio, rather than a particular crop. Accordingly, we will test this proposition in Section III of this Chapter.

TABLE VI-3 continued

B. Zone Four, Kikuyu Grass Zone

	Local Maize	Coffee	Tea	Improved Dairy
Land	4	2½	1	2½
Family Labor	4	2	1	3
Hired Labor	2	3	-	-
Purchased Inputs	2	3	-	4
Capital	2	-	-	4
Coefficient of Variation	0.4	0.2	0	0.2

C. Zone Five, Star Grass Zone

	Local Maize	Hybrid Maize	Cotton	Coffee	Unimproved Dairy
Land	4	3	2	1	5
Family Labor	3	1	4	2	5
Hired Labor	4	-	-	2	-
Purchased Inputs	4	1	-	2	5
Capital	4	1	-	-	5
Coefficient of Variation	0.1	0.5	0.3	0.2	0.0

TABLE VI-3 continued

D. Zone Six, Mixed Ecological Zone

	Local Maize	Unimproved Dairy
Land	2	1
Family Labor	1	2
Hired Labor	1	-
Purchased Inputs	1	2
Capital	1	2
Coefficient of Variation	0.3	0.2

While these results are not completely satisfactory, they are consistent enough to indicate the ordering of crops on the basis of the marginal value product. In only three of the seventeen cases was the coefficient of variation greater than 0.3, and in only one case was it greater than 0.5. The failure of the production function results to provide a consistent ranking across all inputs can be ascribed to the various constraints which limit the farmer's ability to freely allocate resources in the short-run.

II. ECONOMIC EFFICIENCY

We have argued that the only profit-maximizing test of economic efficiency that holds in our model is that the ratios of the marginal products of any two factors into a given crop, i, should be equal to the ratio of the marginal products of those same two factors into any other crop j. In order to test this proposition our sample was divided into eighteen subsamples representing different cropping patterns. For example, all farms in Zone three producing maize, coffee, and improved dairy, and nothing else, were separated into a subsample and tested for the equality of any pair of ratios of marginal product. In particular, we chose those factors over which the farmer had some freedom of allocation--land/family labor for those crops which were not permanent; family labor/hired and family labor/purchased were otherwise appropriate.

These ratios were then tested by means of paired t-tests to see if the sample means of any pair of ratios were significantly different from each other. The results are presented in Table VI-4. Although interpretation of these results involves some degree of subjectivity, it seems fair to state that farmers in Kenya are relatively efficient in their allocation of resources among crops.

TABLE VI-4

RESULTS OF TEST OF ECONOMIC EFFICIENCY

Input Pair	Number of t-tests in which sample means of ratio pairs were not significantly (5%) different	Number of t-tests for which sample means were significantly different
Land/Family Labor	25	4
Family Labor/Purchased Inputs	13	3
Family Labor/Hired Labor	6	0
Total	44	7
Percentage of Total	86.3%	13.7%

III. RISK AND ECONOMIC EFFICIENCY

Thus far we have found the following:

(1) Farmers are constrained in their total usage of modern factors (such as hired labor, purchased inputs, and modern forms of capital);

(2) Farmers are efficient in their allocation of resources among crops.

It is also obvious from Table VI-1 that the marginal value product of any input in each of its uses are not equal. In Chapter III we predicted this phenomenon, explaining it by means of our model of farmer behavior under conditions of uncertainty. We argued that, the higher the marginal value product, the higher the marginal increment to risk, and conversely. To test this proposition, let us examine the same subsamples that we used in examining allocative efficiency. There are eighteen of these sub-samples of identical cropping patterns; of these, nine groups grow only two crops, another six grow three crops, and three grow four different crops. Altogether this means that there are 45 possible pairings of crops; of these forty-five pairings, thirty-nine exhibited behavior consonant with our model, i.e., the crop with the higher marginal value product also had the higher marginal increment to risk. These results are shown in Table VI-5.

Thus, it is clear that risk-aversion plays a very important role in farmer behavior; farmers are willing to grow high risk crops only if they get a higher payoff in expected return. Moreover, risk aversion may help explain why farmers are interested in multi-cropping (assuming no joint production). By producing a mutual fund of crops

TABLE VI-5

RESULTS OF TESTS OF RISK AVERSION AND ECONOMIC EFFICIENCY

Number of crops grown in sub-sample	Marginal Value Product Ranked Identically to Marginal Increment to Risk ?	
	Yes	No
2	8	1
3	16	2
4	15	3
Total	39	6
Percentage of Total	86.7%	13.3%

they can get the same range of expected return at lower levels of risk, as they would if they only grew one crop at a much higher risk level [Tobin, 1965].

IV. CONCLUSIONS

In Chapter III we presented a model of farmer behavior under conditions of uncertainty. In Chapter IV we described the data set which we would use to test this model. The results of the estimation procedure were detailed in Chapter V. But these results provided little information, in their raw form, on the validity of the model. In point of fact, had the tests which we performed in the present chapter not validated the model, we would not have known whether the model was misspecified, the estimation procedure incorrect, or the data false. Fortunately, the tests we have performed indicated that our model does provide an accurate representation of farmer behavior.

Certainly, we were justified in our assumptions that farmers were both rational and risk-averse. Moreover, we showed, that if farmers are risk-averse, traditional tests of rational behavior and economic efficiency using profit-maximizing models, ask the wrong questions. One should not expect risk-averse farmers to equate the marginal value product of an input to its price.

The only question of inefficiency raised by our study relates to the under-utilization of total resource use, and this seems easily explained by factor scarcity due to under-developed factor-markets. Having tested the propositions derived from our model, we are ready to return to the problem raised at the beginning of this study--the calculation of short-run supply elasticities. This will be the subject of the final chapter.

CHAPTER VII

CONCLUSIONS

This, the concluding chapter, is actually comprised of two parts: the first half deals with the calculation of the farmer's supply response to price under conditions of uncertainty; the second half summarizes our findings and suggests area for further research.

In Section I we derive and analyze the results of our calculations of price-response. In particular, we show that the presence of risk makes negative supply elasticities for a given crop explicable, although price increases should lead to a positive change in total agricultural output. We then present the results of our calculations. In Section II we summarize the study, outlining the four major conclusions pointed out by our results with reference to farmer behavior in Kenya. The policy implications of our study, with particular reference to pricing policy, the social assumption of private risk, and the improvement of marketing institutions, are presented in Section III. We conclude this chapter with suggestions for further research.

I. THE SUPPLY RESPONSE TO PRICE OF KENYAN FARMERS

We have assumed that farmers are both risk averse and efficient in their allocation of scarce resources. What do these assumptions imply about short-run price response elasticities? We have described in Chapter III the method which we will employ in calculating these elasticities, but it might be well to briefly review the procedure and the implications of these short-run elasticities.

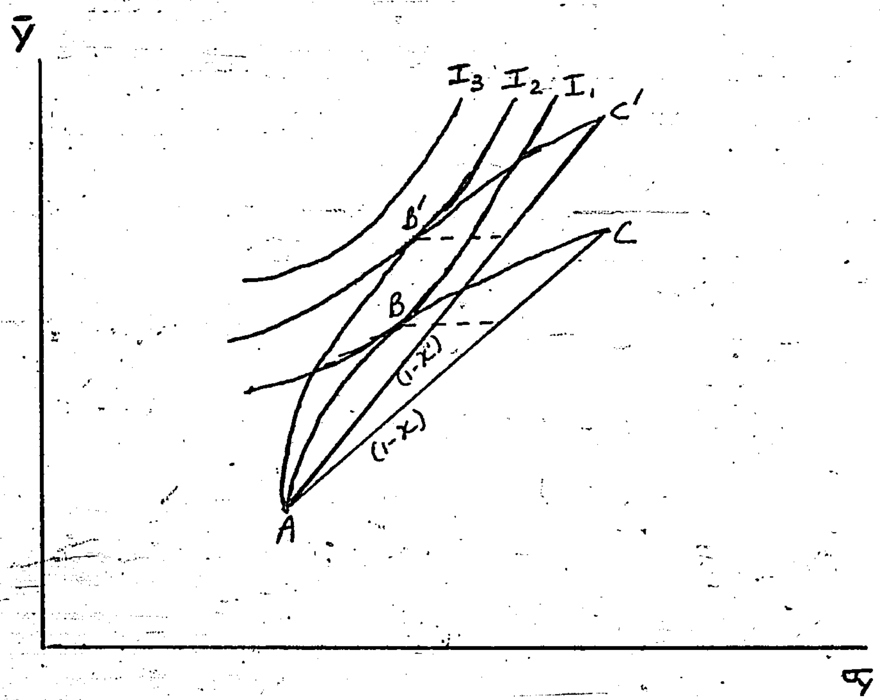
The expected utility maximization conditions represented by equation 3.15 (p. 42) demonstrate that the farmer chooses that allocation of resources which equates the marginal utility of the additional income generated by increasing any input level to the marginal disutility of the additional risk incurred by such an increase. Thus, any farmer who is economically rational in his allocation of resources, will, upon a change in the exogenous price vector, shift his resource mix in such a way as to maintain this balance (excluding the costs of such a shift). Since we are dealing with the relatively short-run (crop year) during which the scope for resource shifts is severely limited, we would not expect these supply elasticities to be anywhere near as large as the long-run elasticities generally estimated in price-response studies.

The way in which he shifts his resources is represented by equation 3.22 (p. 45) which is derived by totally differentiating the first-order conditions. We have already stated that we do not expect the magnitude of these shifts to be very large, but we have, as yet, said nothing about the signs. The utility function which we have chosen, the semi-logarithmic Bernoulli function, exhibits the property of decreasing absolute risk aversion.[1] Thus, as expected income

[1]The assumption of the semi-logarithmic form for the farmer's utility function has not been essential up to this point. In other words, none of the results which we have derived so far depend upon any specific formulation for the utility function. While we can provide no evidence concerning the specific semi-logarithmic form for the utility function, there is a good deal of inferential evidence that the function must exhibit decreasing absolute risk aversion, i.e., that wealthier farmers are willing to take on more risk (cf., for example, p. 65).

increases, the farmer should be more willing to take on risk in order to ensure greater expected return. In somewhat more familiar terms, the income effect of a change in a given output price, is positive, leading to increased production of the given output. However, the increase in any output price may increase risk by more than it increases expected return. Thus, there is no a priori statement we can make concerning the sign of the substitution effect, and it is therefore not at all clear that an increase in the price of any commodity will have a positive supply elasticity. This is illustrated in the two commodity case in figure 7.1, where ABC represents the original opportunity locus after an increase in the price of the riskier asset, and I_1, I_2, and I_3 are indifference curves of the semi-logarithmic utility function.

Fig. VII.1. The Effect of a Price Increase on Input Choice



Points C and C' represent the combination of risk and expected return which pertain if only the risky crop is grown. Points B and B' are the equilibrium positions before and after a price rise, respectively. The proportion of expected return produced by the risky crop before and after the price shift is represented by the fraction (1-x)/AC and (1-x')/A'C'. Whether or not this proportion increases depends on the shape of the opportunity locus, which in turn depends on the particular parameters of the production functions and the variance-covariance matrix. Thus both positive and negative elasticities represent rational behavior, although both total risk and total expected return will rise with an increase in an output price. The results of the price response calculations are presented in Table VII-1.

II. SUMMARY

It might be well at this point to review some of the major findings of this study. In Chapter I we set out the following questions to be answered: What effect does risk have on farmer behavior? Are farmers efficient in their allocation of scarce resources? What are the bottlenecks that limit agricultural production? How responsive are farmers to changes in the price vector?

We then, in Chapter II, presented a description of agriculture in Kenya, in order to, first, provide a general statement of the importance of agriculture within the Kenyan economy, and, second, identify those ecological and institutional constraints which influence farmer behavior. Thus we examined, albeit briefly, the great spatial and temporal variety of climatic conditions, and suggested that the seasonal

TABLE VII-1

MEAN ELASTICITY OF OUTPUT WITH RESPECT TO OUTPUT PRICES

A. Balanced Ecological Zone, Zone Three

	Price			
	Maize	Coffee	Pyrethrum	Milk
Inputs				
Family Labor	-0.6717	-0.0156	-0.0555	0.0230
Hired Labor	0.0914	-0.0353	0.0198	0.1446
Purchased Inputs	-0.0033	-0.0034	0.0042	0.0149
Outputs				
Local Maize	0.0381	0.0518	-0.0380	-0.0764
Hybrid Maize	0.0611	0.1106	-0.0416	-0.1070
Coffee	0.0644	-0.0062	-0.0008	-0.0286
Pyrethrum	-0.0039	0.0004	0.1782	-0.0001
Improved Dairy	0.1124	-0.0003	-0.0024	0.1211
Unimproved Dairy	-0.0881	-0.0065	-0.0692	0.1944

TABLE VII-1 continued

B. Kikuyu Grass Zone, Zone Four

	Price			
	Maize	Coffee	Tea	Milk
Inputs				
Family Labor	0.0035	-0.0149	0.0118	0.2234
Hired Labor	0.0051	-0.0015	0.0011	0.3112
Purchased Inputs	-0.0306	0.2303	-0.1115	-0.0814
Outputs				
Local Maize	0.0201	-0.0517	-0.0019	0.2231
Coffee	0.0300	0.1344	0.0211	-0.0199
Tea	0.0561	0.0404	0.2245	-0.0466
Improved Dairy	-0.0144	-0.0771	-0.1023	0.4432

C. Star Grass Zone, Zone Five

	Price			
	Maize	Cotton	Coffee	Milk
Inputs				
Family Labor	0.0654	0.1345	0.0234	0.0055
Hired Labor	0.1432	-0.0583	0.0662	-0.0572
Purchased Inputs	0.0237	-0.0249	-0.0437	0.0002
Outputs				
Local Maize	0.4672	0.0455	0.0234	-0.0335
Hybrid Maize	0.5237	0.0722	0.0511	-0.0722
Cotton	0.0035	0.0712	0.0008	0.0000
Coffee	-0.1335	0.0004	0.0237	-0.0187
Unimproved Dairy	-0.0449	0.0000	-0.1175	0.2213

TABLE VII-1 continued

D. Mixed Ecological Zone, Zone Six

	Price	
	Maize	Milk
Inputs		
Family Labor	0.2213	0.1448
Hired Labor	0.0788	-0.0006
Purchased Inputs	0.0922	-0.0044
Outputs		
Local Maize	0.1543	-0.0055
Unimproved Dairy	-0.0009	0.0784

variation made agricultural production very risky, and that, consequently, it would be inappropriate to examine farmer behavior without considering the importance of risk.

While the natural world imposes an additional problem upon the farmer, the social (institutional) world limits his opportunities for achieving an optimal solution. In particular, neither product nor factor markets work efficiently. There are, for example, two prices for maize--a buying and selling price. The existence of this dual price system increases risk to the farmer and causes a host of non-commercial considerations to enter into the production of maize.

In addition to the dual price system for maize, there are also acreage restrictions in the planting of coffee and pyrethrum; inefficient capital markets that limit the farmer's ability to purchase modern inputs; and tribal prejudices that limit the supply of hired labor. All of these market imperfections act as constraints on the farmer's allocations of resources, and should be explicitly presented in any model of farmer behavior in Kenya.

In the analytical section, Chapter III, we traced out the implications of a neoclassical model of farmer behavior in Kenya under conditions of uncertainty. We showed that maximizing expected utility was equivalent (under the assumption that the distribution of the random variable, income, was normal) to maximizing a modified utility function with two arguments--expected return and the variance of income.

Using this mean-variance framework we derived the behavioral response to price of farmers acting according to the model, and put forward two testable hypotheses:

(1) A farmer will have no reason to equate the marginal value product of any input to the input's price, and consequently, will not equate the marginal value products of any input in each of two uses. Thus, using the equation of marginal value product and input price as a criterion for economic efficiency is invalid, for it is founded on the assumption that "risk," the variance of income, plays no part in the farmer's calculation. If "risk" is indeed important in the farmer's calculations, then one would expect that the marginal value products of all inputs into the high risk/high return crop would be systematically higher than the marginal value products of the low risk/low return crops.

(2) The ratio of the marginal products of any two inputs in any pair of uses will, in fact, be equal to the price ratio of the inputs, and equal to each other.

We then proceeded to estimate the important parts of the model--the variance-covariance matrix, and the cross-sectional Cobb-Douglas production functions for eight enterprises across four ecological zones. The data set which we used was the Small Farm Sample Costs Survey, administered by the Kenyan Government, which contained observations on inputs and outputs for a nation-wide sample of 1351 farms. Analysis of the marginal value products of these seventeen production functions led to the following set of conclusions:

(1) Farmers were constrained in the total quantity of resources they were able to use by imperfections in factor markets.

(2) Farmers were efficient in their allocation of resources across crops.

(3) Farmers were risk-averse and tended to employ fewer resources in high-return/high-risk crops than would be predicted by profit maximization theory.

(4) Short-run elasticities of output with respect to output prices were higher than expected, though some turned out to be negative.

III. POLICY IMPLICATIONS

In many ways the present policy is more suggestive than conclusive, but several of our results have important implications for governmental policy toward smallholder agriculture. While these implications can be divided into questions of risk, marketing institutions, and pricing policy, all of these categories are intimately related to each other.

There can be no doubt that the presence of risk leads farmers to make decisions which are not efficient from a social point of view, though they very well may be efficient from the farmer's own perspective. This is true since (1) the society should be willing to assume higher risk in order to obtain higher rates of return (decreasing absolute risk aversion), and (2) the economy is able to pool disturbances geographically, thus effectively reducing total social risk. Thus, in theory at least, the government should be willing to take on the farmer's risk, through some method of guaranteeing minimal expected return. Practically, although this policy was used with great effect in the large farm sector during the pre-war period, the problems of administering such a program throughout the entire small farm sector would be monumental [Ghai and McAuslan].

Still, there are many ways in which the government can act so as to reduce risk for the farmer. For example, the reduction of the gap between the buying and selling price of maize would be of immeasurable significance, if it were coupled with the assurance that maize supplies would be available in case of shortages. Any set of policies that would act to shift maize toward the category of cash crop, coupled with more liberal provision of credit, thus reducing the farmer's year to year risk, would doubtless lead to the farmer's engaging in choices that would increase expected return.

In short, then, the problems of pricing policy, and risk, as well as those caused by a shortage of credit, imply that great efforts must be made to improve factor markets. This is especially true for capital markets where increased capital availability would decrease risk to the farmer, allow increased use of modern inputs, encourage a shift in technique from traditional crops such as local maize to hybrid maize, and thus generate increased wage employment in agricultural areas.

The present study has many defects. Some of these are due to deficiencies in the data set, which have already been noted. Others are due to lack of data, particularly times-series micro-level information, which prohibited study of the more interesting long-run supply response. Still others are due to simplifications in the model and estimating techniques necessitated by our own time constraints. Nevertheless, what we have learned should encourage further research along these lines, for it is only by learning how farmers do, in fact behave, that the economist can offer suggestions that will help develop the government policy set which will encourage the development of the rural sector.

APPENDIX I

TIME SERIES OF PRICE AND MARKETED OUTPUT FOR SMALL FARMS

BY DISTRICT

I. KISII DISTRICT

	Price of Tea (sh/lb.)	Output of Tea (lbs)	Output of Coffee ('000's of Tons)	Marketed Output of Maize ('000's of Bags)
1957	--	--	259.95	
1958	--	--	469.41	
1959	--	--	610.74	69032
1960	--	--	975.67	22223
1961	.42	225186	1136.62	30917
1962	.44	535709	704.54	19584
1963	.47	807388	2023.81	5839
1964	.48	1863473	1722.39	20839
1965	.48	2994510	3423.53	81106
1966	.49	2654488	1660.42	40586
1967	.415	5627855	3213.43	16463
1968	.43	7968143	2468.75	188202
1969	.47	9826568	1908.45	134862

II. BUNGOMA DISTRICT

1957			100.37	
1958			148.08	
1959			282.19	266247
1960			445.40	249372
1961			515.10	188940
1962			616.00	246506
1963			637.97	106130
1964			365.54	171815
1965			433.04	292108
1966			484.81	464228
1967			156.79	689288
1968			597.61	533608
1969			305.76	412841

III. BUSIA DISTRICT

	Marketed Output of Maize ('000's of Bags)	Coffee Output ('000's of Tons)
1959	27867	
1960	22864	
1961	23173	
1962	25929	
1963	3052	
1964	17674	
1965	18607	
1966	43761	
1967	63919	
1968	19646	
1969	2662	

IV. SIAYA AND KISUMU DISTRICTS

	Marketed Output of Maize ('000's of Bags)	Coffee Output ('000's of Tons)
1957		.09
1958		.03
1959	10251	.04
1960	7927	0
1961	4624	.60
1962	6487	16.77
1963	2306	2.22
1964	3258	25.67
1965	29176	12.08
1966	334	5.01
1967	7002	19.96
1968	3136	11.42
1969	0	8.02

V. NANDI DISTRICT

	Tea Output (lbs)	Price of Tea (sh/lb.)	Output of Coffee ('000's of Tons)	Marketed Maize Output ('000's of Bags)
1959	--		.39	66099
1960	--		1.74	53168
1961	14332	.45	1.60	31202
1962	61150	.46	6.08	35093
1963	100416	.47	9.98	10965
1964	211294	.48	24.26	13885
1965	532861	.48	30.73	121870
1966	580645	.49	26.90	193861
1967	2465665	.47	10.84	151976
1968	2419926	.43	10.08	217475
1969	4410167	.45	4.94	114663

VI. TAITA DISTRICT

1957			15.62	--
1958			24.44	--
1959			32.36	--
1960			60.00	--
1961			65.90	--
1962			87.80	--
1963			119.95	--
1964			96.57	--
1965			86.73	3718
1966			70.31	50
1967			62.15	--
1968			32.07	--
1969			36.51	--

VII. KERICHO DISTRICT

	Tea Output (lbs)	Price of Tea (sh/lb.)	Output of Coffee ('000's of Tons)	Marketed Maize Output ('000's of Bags)
1959	--	--	--	10217
1960	--	--	1.60	6985
1961	540142	.44	.12	3291
1962	545057	.43	.17	21690
1963	818295	.47	9.59	597
1964	1676260	.48	7.84	9466
1965	2576294	.48	16.13	28995
1966	2702252	.49	5.69	40251
1967	5443027	.41	14.96	57744
1968	6723666	.44	14.07	161536
1969	10156598	.49	7.52	17450

VIII. NYANDARUA DISTRICT

1959				9456
1960				43422
1961				60932
1962				54724
1963				44602
1964				34107
1965				39759
1966				75992
1967				5428
1968				11904
1969				33606

IX. KIAMBU DISTRICT

1958	--	--	10.31	
1959	--	--	79.50	1771
1960	--	--	199.00	1909
1961	75398	.42	419.37	2290
1962	270950	.49	451.63	17145
1963	545492	.50	853.87	12596
1964	1149384	.54	1268.71	4281
1965	1974666	.53	1740.09	58109
1966	1422312	.54	3558.86	230
1967	2641125	.42	2942.16	0332
1968	3784767	.41	718.04	247
1969	4326292	.45	3089.56	0

X. EMBU DISTRICT

	Tea Output (lbs)	Price of Tea (sh/lb.)	Output of Coffee ('000's of Tons)	Marketed Maize Output ('000's of Bags)
1957	--		386.57	--
1958	--		823.61	--
1959	--		1101.93	3981
1960	--		1945.04	499
1961	--		2051.17	26414
1962	3170		2501.58	26806
1963	18541		1318.99	6395
1964	47935		917.49	5444
1965	308562		1441.83	16945
1966	277676		2347.65	3506
1967	1158398		1837.44	9068
1968	1370041		1371.34	9345
1969	1637067		1667.14	997

XI. KILIFI DISTRICT

	Tea Output (lbs)	Price of Tea (sh/lb.)	Output of Coffee ('000's of Tons)	Marketed Maize Output ('000's of Bags)
1958				--
1959				3786
1960				187481
1961				711478
1962				23240
1963				230
1964				88906
1965				645835
1966				199
1967				54
1968				93
1969				--

XII. NYERI DISTRICT

	Tea Output (lbs)	Price of Tea (sh/lb.)	Output of Coffee ('000's of Tons)	Marketed Maize Output ('000's of Bags)
1958	--	--	252.32	--
1959	--	--	291.32	1404
1960	--	--	588.66	162
1961	1459900	.48	449.26	3767
1962	1946400	.56	941.20	2185
1963	2228300	.50	1063.12	152
1964	3887800	.54	1182.60	3272
1965	4640500	.53	2343.48	20480
1966	4073600	.54	3817.07	1213
1967	12792700	.42	2223.59	14062
1968	15789700	.41	2936.78	339
1969	15437400	.45	3462.06	64

XIII. MURANG'A DISTRICT

	Tea Output (lbs)	Price of Tea (sh/lb.)	Output of Coffee ('000's of Tons)	Marketed Maize Output ('000's of Bags)
1958	--	--	179.51	--
1959	--	--	362.36	6992
1960	--	--	652.87	3934
1961	2500	.48	701.20	20414
1962	24000	.56	840.00	50974
1963	94800	.50	1700.50	24050
1964	333600	.54	1683.22	11914
1965	1043700	.53	3652.34	117306
1966	1030600	.54	4509.52	154
1967	2891200	.42	1549.00	9248
1968	3784700	.41	3714.20	1674
1969	4563200	.42	4069.84	13

XIV. KIRINYGA DISTRICT

	Tea Output (lbs)	Price of Tea (sh/lb.)	Output of Coffee ('000's of Tons)	Marketed Maize Output ('000's of Bags)
1959	--	--	--	7376
1960	--	--	--	750
1961	--	--	--	43056
1962	983878	.56	--	40928
1963	1221272	.50	1853.74	9602
1964	1907638	.54	1845.86	8416
1965	2482307	.53	2594.74	31358
1966	1999249	.54	4324.60	24153
1967	5257793	.45 1/2	2574.34	72879
1968	6165182	.44	2269.43	42991
1969	8185335	.52	1714.59	4929

XV. MERU DISTRICT

	Tea Output (lbs)	Price of Tea (sh/lb.)	Output of Coffee ('000's of Tons)	Marketed Maize Output ('000's of Bags)
1957	--	--	973.05	--
1958	--	--	1586.03	--
1959	--	--	1604.68	95734
1960	--	--	2397.62	90174
1961	--	--	2392.51	53379
1962	43407	.56	3752.58	76637
1963	147857	.50	4278.35	53260
1964	455529	.54	3941.82	62862
1965	698172	.53	6230.31	63498
1966	1353169	.54	5539.16	35690
1967	3800062	.47 1/2	6351.16	35832
1968	4363742	.50	5200.65	34024
1969	6422379	.51 1/2	7673.50	81893

SOURCES:

Columns one and two: The Kenya Tea Development Authority.

Column three: The Coffee Marketing Board of Kenya

Column four: The Maize and Produce Board

SMALL FARM COUNTRY-LEVEL DATA

	Price of Coffee	Output of Pyrethrum	Price of Pyrethrum	Output of Cotton	Output of Milk
1959	39.93	0.6	180.10	10.0	--
1960	35.84	1.8	186.69	11.0	--
1961	33.54	2.8	155.59	9.0	--
1962	33.88	2.7	126.68	5.3	--
1963	29.03	1.8	129.03	8.7	953
1964	35.56	2.2	144.86	10.8	1456
1965	33.89	3.3	172.22	12.2	1160
1966	33.26	6.8	172.22	13.1	1451
1967	29.62	9.6	180.00	12.5	1885
1968	34.22	--	156.55	14.5	--
1969	30.90	--	159.05	13.7	--

SOURCE: Republic of Kenya, Statistics Division, Ministry of Finance and Economic Planning, Statistical Abstract, 1970, (Nairobi: Government Printer, 1971), p. 72.

APPENDIX II

TIME SERIES REGRESSIONS

A. OUTPUT REGRESSIONS (Figures in parentheses are standard errors)

1. Siaya District

$$\ln(OutCof) = \underset{(0.8902)}{-3.02185} + \underset{(0.1492)}{0.30689}\,T \underset{(1.2482)}{-2.15154}\,\ln(PCof_{-1})$$

$$R^2 = 0.7329 \qquad D\text{-}W = 1.9982$$

$$\ln(OutMze) = \underset{(1.9523)}{10.4822} \underset{(0.2919)}{-0.59046}\,T \underset{(0.06746)}{+0.046324}\,\ln(PMze)$$

$$R^2 = 0.3583 \qquad D\text{-}W = 2.0283$$

2. Kiambu District

$$\ln(OutCof) = \underset{(0.4002)}{4.53934} \underset{(0.0670)}{+0.19968}\,T \underset{(0.5613)}{-1.1111}\,\ln(PCof_{-1})$$

$$R^2 = 0.8258 \qquad D\text{-}W = 1.9758$$

$$\ln(outMze) = \underset{(1.9542)}{9.38285} \underset{(0.2922)}{-0.72429}\,T \underset{(0.06752)}{+0.10779}\,\ln(PMze)$$

$$R^2 = 0.4356 \qquad D\text{-}W = 2.2415$$

$$\ln(OutTea) = 9.97372 + 0.399209\,T - 1.06349\,\ln(PTea_{-1})$$

3. Taita District

$$\ln(OutCof) = \underset{(0.28028)}{2.94934} \underset{(0.04696)}{-0.0246}\,T \underset{(0.3905)}{-1.32333}\,\ln(PCof_{-1})$$

$$R^2 = 0.6712 \qquad D\text{-}W = 1.2461$$

4. Nyeri District

$$\ln(OutCof) = \underset{(0.2089)}{5.29253} \underset{(0.03508)}{+0.229497}\,T \underset{(0.29296)}{-0.278406}\,\ln(Pcof_{-1})$$

$$R^2 = 0.9220 \qquad D\text{-}W = 1.9679$$

$$Ln(OutMze) = 6.54774 - 0.24631\ T + 0.07993\ Ln(PMze)$$
$$(1.4292) \quad (0.2137) \quad (0.04938)$$

$$R^2 = 0.2513 \qquad D\text{-}W = 2.0261$$

$$Ln(OutTea) = 5.9242 + 0.3261\ T + 0.079437\ Ln(PTea_{-1})$$
$$(0.3027) \quad (0.0497) \quad (0.53541)$$

$$R^2 = 0.9316 \qquad D\text{-}W = 2.4806$$

5. Murang'a District

$$Ln\ (OutCof) = 5.20427 + 0.20685\ T - 0.69463\ Ln(PCof_{-1})$$
$$(0.29106) \quad (0.04877) \quad (0.40817)$$

$$R^2 = 0.8747 \qquad D\text{-}W = 2.0729$$

$$Ln\ (OutMze) = 10.4638 - 0.67337\ T + 0.096197\ Ln(PMze)$$
$$(1.69122) \quad (0.2529) \quad (0.09619)$$

$$R^2 = 0.4702 \qquad D\text{-}W = 2.7517$$

$$Ln(OutTea) = -1.25943 + 0.75312\ T - 1.25943\ Ln(PCof_{-1})$$
$$(0.87937) \quad (0.1444) \quad (1.53274)$$

6. Nandi District

$$Ln(OutCof) = 0.12816\ T - 1.30931 - 2.2936\ Ln(PCof_{-1})$$
$$(1.1846) \quad (0.8932) \quad (1.05904)$$

$$R^2 = 0.6399 \qquad D\text{-}W = 0.6596$$

$$Ln(OutMze) = 10.1311 + 0.28906\ T - 0.03863\ Ln(Pmze)$$
$$(0.6989) \quad (0.1267) \quad (0.03537)$$

$$R^2 = 0.4262 \qquad D\text{-}W = 1.4536$$

$$Ln(OutTea) = 7.07334 + 0.640902\ T - 0.93921\ Ln(PTea_{-1})$$
$$(0.3638) \quad (0.048035) \quad (0.51068)$$

$$R^2 = 0.9803 \qquad D\text{-}W = 2.7883$$

7. Kisii District

$$Ln(OutCof) = 8.98438 + 0.006089\ T + 1.14617\ Ln(PCof_{-1})$$
$$(2.2766) \quad (0.07046) \quad (1.9517)$$

$$R^2 = 0.4808 \qquad D\text{-}W = 1.4592$$

$$\text{Ln(OutMze)} = \underset{(0.81658)}{7.86120} - \underset{(0.12216)}{0.035512}\,T + \underset{(0.02822)}{0.07099}\,\text{Ln(PMze)}$$

$$R^2 = 0.5138 \qquad \text{D-W} = 2.0850$$

$$\text{Ln(OutTea)} = \underset{(0.31977)}{12.2054} + \underset{(0.054744)}{0.314036}\,T + \underset{(0.52627)}{0.09565}\,\text{Ln}(\text{PTea}_{-1})$$

$$R^2 = 0.9353 \qquad \text{D-W} = 2.7408$$

8. <u>Nyandarua District</u>

$$\text{Ln(OutMze)} = \underset{(0.637924)}{10.2653} - \underset{(0.095398)}{0.139667}\,T + \underset{(0.022041)}{0.035277}\,\text{Ln(PMze)}$$

$$R^2 = 0.2718 \qquad \text{D-W} = 2.3387$$

9. <u>Kericho District</u>

$$\text{Ln(OutCof)} = \underset{(6.32724)}{-2.06655} + \underset{(0.19218)}{0.41689}\,T - \underset{(6.37291)}{0.198878}\,\text{Ln}(\text{PCof}_{-1})$$

$$R^2 = 0.4802 \qquad \text{D-W} = 1.6895$$

$$\text{Ln(OutMze)} = \underset{(1.02981)}{8.06075} + \underset{(0.154004)}{0.342261}\,T - \underset{(0.03558)}{0.031186}\,\text{Ln(PMze)}$$

$$R^2 = 0.3946 \qquad \text{D-W} = 2.3054$$

$$\text{Ln(OutTea)} = \underset{(0.17119)}{11.5691} + \underset{(0.02257)}{0.41587}\,T + \underset{(0.22927)}{0.439209}\,\text{Ln}(\text{PTea}_{-1})$$

$$R^2 = 0.9863 \qquad \text{D-W} = 2.3145$$

10. <u>Bungoma District</u>

$$\text{Ln(OutMze)} = \underset{(0.81995)}{10.1298} - \underset{(0.12262)}{0.080991}\,T + \underset{(0.028331)}{0.0083255}\,\text{Ln(PMze)}$$

$$R^2 = 0.0532 \qquad \text{D-W} = 1.4364$$

11. <u>NATION-Wide Series</u>

$$\text{Ln(CotOut)} = \underset{(0.14798)}{2.13977} + \underset{(0.021518)}{0.083696}\,T - \underset{(0.169277)}{0.429238}\,\text{Ln(PCot)}$$

$$R^2 = 0.6566 \qquad \text{D-W} = 2.4092$$

$$\text{Ln(PyrOut)} = \underset{(0.38128)}{-0.970417} + \underset{(0.05576)}{0.195835}\ T + \underset{(0.080198)}{0.173067}\ \text{Ln}(\text{PPyr}_{-1})$$

$$R^2 = 0.8450 \qquad \text{D-W} = 0.9057$$

$$\text{Ln(OutMk)} = \underset{(0.73500)}{10.6564} + \underset{(0.029439)}{0.084224}\ T - \underset{(1.68312)}{0.101132}\ \text{Ln(PMk)}$$

$$R^2 = 0.7416 \qquad \text{D-W} = 1.6687$$

B. PRICE REGRESSIONS (Country-Wide)

1. Tea

$$\text{Ln(PTea)} = \underset{(0.09919)}{-0.50448} - \underset{(0.016296)}{0.047471}\ T - \underset{(0.17188)}{0.258715}\ \text{Ln}(\text{PTea}_{-1})$$

$$R^2 = 0.6012 \qquad \text{D-W} = 1.2631$$

2. Pyrethrum

$$\text{Ln(PPyr)} = \underset{(0.12211)}{4.95017} + \underset{(0.029399)}{0.044678}\ T - \underset{(0.10896)}{0.20273}\ \text{Ln}(\text{PPyr}_{-1})$$

$$R^2 = 0.3384 \qquad \text{D-W} = 0.7023$$

3. Coffee

$$\text{Ln(PCof)} = \underset{(0.072644)}{-0.930601} + \underset{(0.069910)}{0.165836}\ \text{Ln}(\text{PCof}_{-1})$$

$$R^2 = 0.3848 \qquad \text{D-W} = 2.8895$$

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