MULTIFACTOR
PRODUCTIVITY CHANGES
IN
ZAMBIAN AGRICULTURE:

The Commercial Subsector

By

FRANCIS M. LONDE

A Thesis Submitted to the University of Manitoba
in Partial Fulfilment of the Requirements
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Abstract

The objectives of this study were to calculate and explain productivity changes for six commercial farm sizes in Zambia. Assuming a common functional form (implied by the translog cost function) for the respective production technologies, productivity indexes were calculated for the period 1978-87 using the tornqvist divisia method and econometrics.

Results indicate a general rise in productivity for medium and large farmers. Index number calculations showed that the smallest producers were more cost-effective than the largest farmers while the opposite was evident from econometrics. Comparisons across groups using dummies also suggest that larger farmers were more productive than smaller ones.

In contrast to econometrics, Tornqvist calculations gave unusually large productivity changes so that econometric results are deemed superior to the tornqvist calculations. Econometric results also suggest that farmers in general were becoming less cost effective as time proceeded so that in the more recent years productivity changes were negative and technical regress was evident.

Statistcal tests revealed that farmers were neither minimizing costs nor maximizing profits and constant returns to scale were rejected. Technological change was found to be embodied and neutral with respect

to scale and labour, but capital-saving, and land-using.

To Mungala and Nampande, to Charity, and to my parents, Nalituba and Hanambe Londe.

Acknowledgements

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Very special thanks to my wife, Charity, for her love and kind support and continued inspiration through these travels. Without her this undertaking would have been much more difficult. Thanks also to all my friends in the Annex for their help in various ways .

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Chapter I

Introduction

1.1 Overview

Zambia, like most development countries, is characterized by a small political elite, low political institutionalization, and an experience of colonization by the western metropolitan powers in the last two centuries. The extended family is the most common institution, with a low technology peasant mode of agricultural production (World Bank, 1988).

The economy of Zambia is small, fairly open and heavily dependent on copper mining. The International Monetary Fund (IMF, 1991) estimates that imports and exports account for more than 40 percent of the Gross National Product. The major source of export earnings is copper, contributing more than 90 percent.

During the last 15-20 years Zambia's economy has deteriorated considerably. In this period Zambia's classification by the World Bank has changed from a middle income to a low income country. In 1987 Gross National Product was estimated at $83 per capita down from US $2081 in 1970, in 1985 prices (IMF, 1991). In the years 1965-1987 the per capita GNP declined at an average annual rate of 2.1%.

Table 1.1 Percentage Contribution to GDP and Growth Rates: Selected Sectors.

	Contribution		Growth	
Sector	1965	1987	1965-80	1980-87
Industry (Non-Manufacturing)	14	8	2.1	-0.7
Manufacturing	6	23	5.3	0.8
Agriculture	14	12	2.2	3.2
Services	32	52	1.5	-0.6

Source: World Bank, *World Development Report, 1990*

The external public debt has become a burden. In 1970 the public debt was US$623 million. However, by 1987 it had exceeded the $4.3 billion mark. The estimates for 1990 exceeded $8 billion (IMF, 1991). As a percentage of GNP external debt was 35.7% in 1970 and 227.5% in 1987. Debt service rose from 3.7% in 1970 to 6.7% of GNP in 1987, with interest payments more than doubling.

The agricultural sector has typical characteristics of a developing economy. It is highly dualistic with a relatively well-developed commercial[1] or market-oriented subsector and a much larger traditional (subsistence) subsector. The traditional farmer, often cultivating less than 2 hectares and employing simple hand tools, produces primarily for own consumption with occasional surpluses for market.

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[1] See the Central Statistics Office definition of commercial farmer, Chapter 3.

Zambia's agricultural sector is also characterized by a land tenure system that essentially is a carry-over from the colonial era. Ownership of the land is vested in the head of state (the President) who holds it for and on behalf of the people of Zambia. Continuing from the colonial times, land is divided between traditional (or reserve) and state land. No one can hold title to traditional land while individuals on state land have freehold or leasehold of up to 99 years.

The agricultural sector has not played a significant role in the development of the economy. Since independence in 1964 agricultural production has declined from 14% to 12% of gross domestic product in 1987 (Table 1.1). Agricultural production grew some 2.2% in the period 1965-80 with a modest increase in this rate to 3.2% between 1980 and 1987 (World Bank, 1989). Agricultural exports were approximately one percent of GDP in the same period. Value added (in current dollars) increased from $191 million in 1970 to $222 million in 1987. In 1987 cereal imports were a staggering 150 000 metric tonnes and food aid frog-leaped more than 2300% during the 17 years since 1970. In short, from a net exporter of grain Zambia was now a net importer, with the gap between domestic production and disappearance widening.

Several causes of this dismal performance of the agricultural sector can be discerned. They range from climatic factors to international economic conditions to domestic policy regimes. Even though little can be done to ameliorate the adverse effects of the international economic environment and climatic factors it is widely believed that a lot can be done about the domestic policy regime. In fact it is widely argued that the interventionist and often conflicting policy approach has been responsible for economic problems more than any other factors (World Bank, 1984; Jansen, 1986, 1988; Geisler, 1992). Such inconsistent policies are also alleged to be the greatest obstacle to the development potential of the country (Mumeka, 1991).

Zambia's agricultural potential is virtually unlimited. Of the estimated 9 million hectares of arable land, only about 16 percent is presently estimated to be cultivated annually. Rainfall is one of the major determinants of agricultural production. Even though the climate is generally favourable for the cultivation of a wide range of crops the rains tend to be erratic. Mid-season droughts are not uncommon. In some years these mid-season droughts have resulted in poor harvests in most parts of the country, leading to serious food shortages. Despite the fact that the country has plenty of water suitable for irrigation only about 0.1% of the potential is being exploited. Most of the country is suitable for livestock production except for a few pockets of tse-tse fly infestation.

Perhaps the most important potential of agriculture lies in its capability to provide employment. Currently it is estimated that agriculture employs more than 50% of the labour force. In the face of rising unemployment elsewhere in the economy agriculture offers the only viable alternative.

1.2 Agriculture and Development

The position of agriculture in the Zambian economy reflects the early 1960s received perception of how development should occur and the role that agriculture should play in the process. Typically, in the now industrialized economies the contribution of agriculture declined as the industrial sector grew during industrialization. Industry was seen as the leading sector. Agriculture followed. This resulted in developing countries adopting policy strategies that aimed at accelerating industrialization by placing emphasis on the transfer of investible resources away from agriculture into industry and the public sector. Agriculture was seen as a pool of resources for the development of the non-agricultural sectors. Labour was assumed to be in excess supply while capital would come from taxes on the rural population or agricultural products.

However, developing countries find themselves faced with situations that are significantly different from those which faced the developed countries before their industrialization, including (i) higher population growth rates, (ii) stiffer competition for commercial export markets, (iii) differential technological advancement between developed and developing countries giving the former a competitive advantage, and (iv) history, which has created a legacy of institutions and commercial structures that shape current options for development (Colman and Nixon, 1986:205). In the case of Zambia industrialization did not occur and there was no surplus labour in agriculture.

1.3 Background to the Problem

Growth of Zambia's agricultural production in the 1970s and 1980s, like the whole economy, lagged behind growth in demand for agricultural products. While population, the main demand shifter, grew at a high rate of 3.4 percent per year agricultural production only rose at about one percent or less. This reduced food self-sufficiency. The crashing of the copper prices on the world market in the mid 1970s increased food insecurity through reduced foreign exchange earnings needed to import the shortfall in production.

The reasons for the poor performance of the agricultural sector are many and varied. However, the biggest hinderance to better agricultural performance is the domestic policy environment. Several recent studies have demonstrated the adverse effects of the interventionist policy approach on agriculture (e.g. Jansen, 1977, 1986, 1988; Wood, et al 1990; Geisler, 1992; Banda, 1991; Mumeka 1991).

Except in a few situations, public regulation of the market is by nature a distortion in the market process. As a result the utility and profit-maximizing decisions of the individual economic agents are altered. Economic theory says that in the absence of externalities, in a smoothly operating market, such regulatory policies would ensure that the private producer deviates from his production frontier, which is assumed to be the optimal. Often this means more inputs are required to produce a given level of output. Equivalently, the rate of growth of output per unit of input, or productivity growth, is reduced. Indeed, it is also entirely possible that government intervention leads to higher productivity.

Policy intervention can be rationalized in a number of ways. The first justification for intervention is the desire to correct for market failures. Market failure implies that the prices of goods and/or services will not reflect their true scarcity values as the private sector is unable to develop institutions for efficient functioning of the market. The market may fail due to such factors as lack of information, market power and externalities (soil erosion, environmental pollution, and overutilization of common properties).

During the 1970s and 1980s Zambia's agricultural policy was one of intervention with particular emphasis on the desire to accelerate income growth and distribution. These have included provision of public goods such as research and development, extension and infrastructural development (schools, roads, health facilities). The main tool of intervention in agriculture was through price and institutional regulation to address income distribution concerns. Producer prices of almost all commodities were set by government. Quite often these prices were set below cost, resulting in a disincentive to producers. Inefficient and sheltered marketing parastatals were used to buy produce from farmers at fixed and uniform prices throughout the country. These agencies were also used to supply farmers with the requisite inputs, though frequently this not done in a timely manner.

Several channels through which price and institutional intervention affects the market process can be distinguished. These include distortions in relative prices among agricultural inputs and commodities and between prices of nonagricultural and agricultural products. The subsidies involved contribute to government budget deficit. Income distribution between large and small producers and between agricultural and nonagricultural occupations is also affected. There are foreign exchange effects, too, since the relative domestic and import prices are also distorted.

Finally price intervention also affects agricultural production. Agricultural production may decline as a result of producers cutting down on their scale, going out of production, a decrease in productivity, or a combination of these. In turn, productivity may decline or producers may scale back or move out of production as a response to government policy.

Over the years Zambia's agricultural production has declined. The general policy disincentives to producers caused per capita agricultural production to decline, resulting in increased food imports. In the case of maize, the country's staple, while area cultivated has increased probably as response to a rise in producer prices, yield has remained virtually unchanged since 1965 (Jansen, 1988).

1.4 Problem Statement

Different policy strategies can be taken to stimulate development of the agricultural sector. In Zambia's case a number of policies were adopted specifically aimed at supporting small scale producers while encouraging the larger farmers to produce nontraditional export commodities (NCDP, 1989:91-114). The underlying assumption for this approach was that costs for small producers are declining so that these farmers only have to increase their scale of operation for the sectoral production to rise. On the other hand it was believed that the large producers needed policies that would lower their average cost of production (see Figure 1.1). It is important, therefore, to assess the impact of the general policy environment in the 1980s on the different sizes of producers. That is, how did this policy regime affect factor

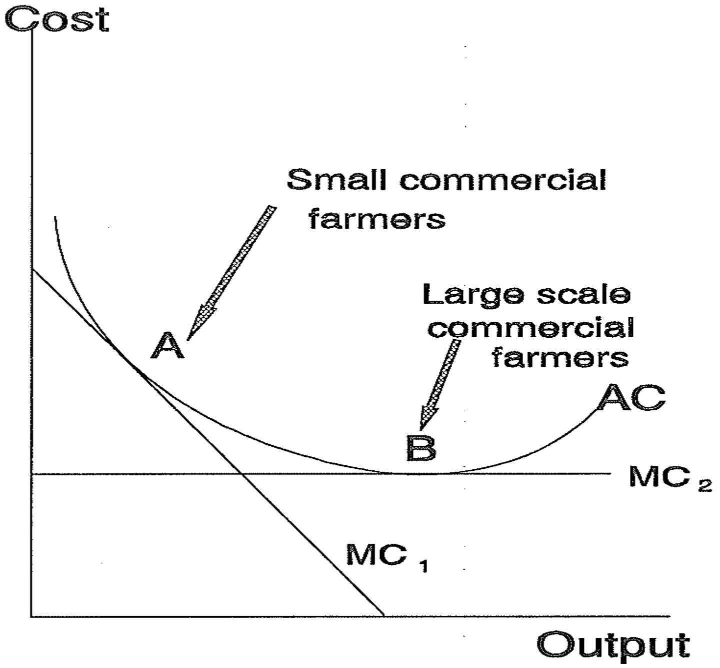

Figure 1.1 Conceptual Relative Positions of Small and Large Scale Producers on the Average Cost Curve.

productivity of the different sizes of farmers?

1.5 Objectives, Scope and Organization

The general objective of this study is to assess changes in total factor productivity (or technical change) among commercial farmers in Zambia. Specifically this study has two objectives:

(i) To measure changes in multifactor productivity for six farmsize groups, and

(ii) To explain the variation in the multifactor productivity indexes of the different groups.

Availability of data limits the study to the years 1978 to 1987.

Nevertheless, this period is characterised by a policy regime of subsidized input prices and fixed output prices.

The study is organized as follows. Chapter 2 reviews the related literature. This chapter also gives the theoretical foundations of the productivity measurements and specifies the analytical models used in this study. Chapter 3 gives a synoptic description of the data and Chapter 4 discusses estimation techniques and the results. Conclusions are presented in Chapter 5.

Chapter 2

Theory and Analytical Models

This chapter reviews the relevant theoretical and empirical studies. Special problems encountered in measuring changes in multifactor productivity (MFP) are highlihgted. Lastly, this chapter presents the analytical models of the study.

2.1 The Production Function

Before we proceed to look at the different studies on productivity changes, it is helpful to first address some house-keeping matters. Accordingly we begin with some definitional issues.

The construct of the production function is the bedrock of the theory of production economics. A production function may be defined as a mathematical or quantitative representation showing the technical relationship between inputs and outputs in a production process (Shephard, 1970; Chambers, 1988). It is a representation of the production technology. The production function is purely a technical relationship (Shephard, 1970). It gives the maximum level of output that can be obtained from a given bundle of inputs. There are no price or cost considerations incorporated into it.

A thorough understanding of the production function is essential for the understanding of the underlying technology. This is extremely important because development of plausible theories and formulation of consistent policies requires a good understanding of the production technology. To this end the production function is the logical starting point.

2.2 Productivity

Productivity denotes a relationship between output and the inputs actually used in production. Often productivity is interpreted as output per unit of a single input. This is also referred to as partial productivity. Productivity is also sometimes interpreted as the ratio of output to all the inputs used in production. To emphasize the difference between the two concepts the term total (or multi-) factor productivity is used to refer to the latter.

Productivity change is often measured as the change in the ratio of outputs to inputs (Nadiri, 1971). Figure 2.1 shows the neoclassical single output single input production function f. At the point R, the average multifactor productivity is the ray OR. Similarly a ray from the origin through T indicates the average MFP with input levels at x_2 and y_2 output quantity (x_1 and x_2 may be one firm at two points in time, or two firms at a point in time). Change in total factor productivity is then the difference between the two rays, the angle represented by ß.

Assuming an initial productive activity level at Q (inside the production function f_1), we can isolate three different phenomena to

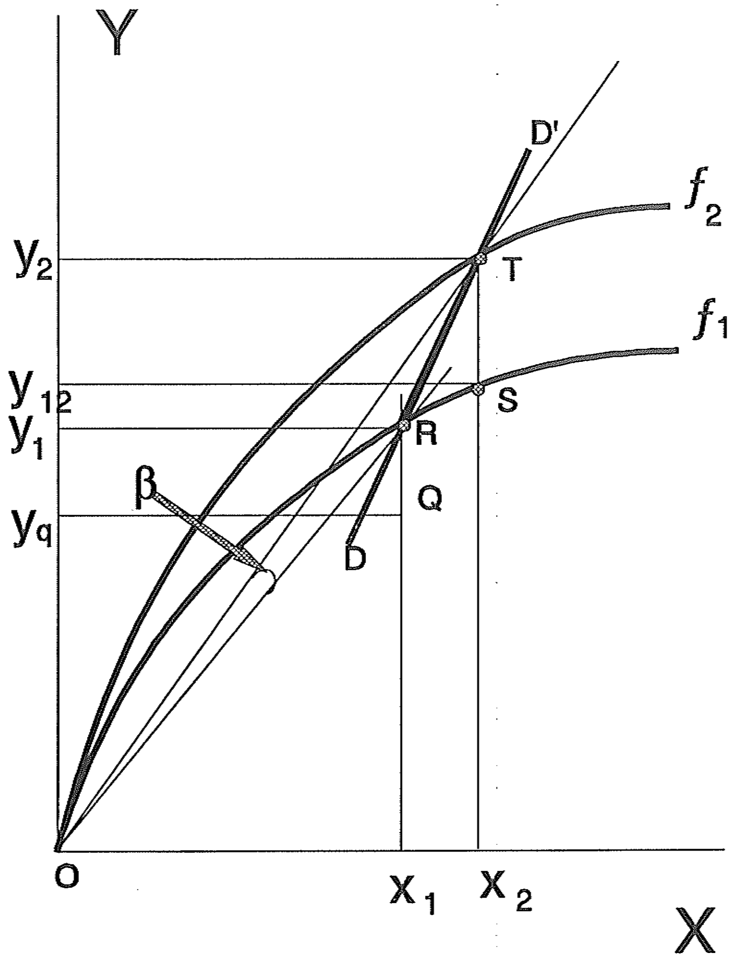

Figure 2.1 The Production Function and Productivity Changes.

which we can attribute changes in productivity:(i) improvement of technical efficiency which is indicated by the movement from *Q* to the production function at, say, *R*, or the effect of improved technical efficiency, (ii) movement from *R* to *S*, the scale effect, and (iii) movement from *S* to *T*, that is, the impact of improvement of technical practices. Thus, differences in the productive efficiency, the scale of operation, and the state of the technology may all explain, in part, the observed differences in the MFP (Solow, 1957; Jorgenson and Griliches, 1967; Capalbo, 1988).

Productivity measures by themselves are irrelevant. Their importance is derived from comparisons of the ratios for particular units, industries, or sector over time or across countries or regions (Kendrick, 1977:13). In general we are interested in productivity measures for the following reasons:

(i) Advances in productivity results in saving in the use of scarce resources per unit of output.

(ii) In the economically advanced countries rising incomes per capita has been in large part due to increases in productivity.

(iii) Within a particular economy differential changes in productivity by industry affects the composition of the gross national product and employment and income distribution.

(iv) In international comparisons, differences in trends in productivity between countries creates differences in growth of real income per capita. These differences also contribute to variation in purchasing power of respective currencies. By influencing relative prices and costs, international differences in productivity changes affect the relative competitiveness of industries in international trade.

(v) In order to increase productivity we need to know the factors (and about these factors) that influence it. These include investment in research and development, education and training, health, safety and mobility (designed to improve the quality and efficiency of the human and nonhuman capital in which they are embodied). Other factors affecting growth in productivity are: economies of scale, changes in economic efficiency, changes in the inherent quality of the resources, rates of capacity utilization, and changes in actual labour efficiency relative to potential under given technologies.

Abramovitz (1962) suggested that the change in total factor productivity is the effect of costless advances in applied tecinology, managerial efficiency and industrial organization. Solow had earlier (1957) termed this technical change. In his words, "...technical change is a shorthand expression for any kind of shift in the production function; ...slowdowns, speedups, improvements in the education of the labour force and all sorts of things...". The shifting of the production function may be accompanied by movement along a production function. Jorgenson and Griliches (1967) emphasize that changes in the patterns of productive activity must be separated into the part which is "costless," representing a shift in the production function, and the component which represents the employment of scarce resources with alternative uses, or the movement along the production function.

2.3 Productivity Changes and Technical Change

Sometimes it is important to distinguish between changes in multifactor productivity and technical change. Increases in capacity utilization can lead to an improvement in total factor productivity but not necessarily to technical change. On the other hand, advances in the technology of production (or technical change) will result in rising total factor productivity. Nonetheless, under some restrictive conditions of constant returns to scale and perfect competition in input and output markets (Baltagi and Griffin, 1988) the two measures are equivalent.

MultiFactor productivity may improve due to, among other factors, increase in technical efficiency and technological change. Farrell (1957) offers one definition of technical efficiency; namely, the observed ratio of inputs per unit of output to the level of output that a perfectly efficient firm would produce from any given combination of inputs. In this sense then an increase in technical efficiency entails movement of the firm from a point within the production possibility frontier to the frontier (from Q to m in Figure 2.1). On the other hand technical change is understood to embody movement of the production possibilities frontier. This implies change of the parameters.

2.4 Productivity Measurements

There are several approaches to measuring changes in productivity, depending on the assumptions made about the underlying technology. Often constant returns to scale and perfect competition are assumed. Three basic methods of measuring or calculating total factor productivity (or technical change) can be discerned in the literature:

(i) Non-econometric parametric calculations of index numbers in which the functional form of the underlying technology is specified but not estimated.

(ii) Econometrics, in which the form of the underlying function is specified and estimated.

(iii) Nonparametric calculations in which the functional form of the production technology is not specified, let alone estimated.

2.4.1 Index Numbers

Productivity measurements using index number calculations involve aggregating across individual commodities, agents, industries or circumstances. There are several methods of aggregating. Consequently, an index number may be good or bad, depending on how it is constructed. That is, it may be biased or unbiased in its representation of the component individuals. It is desirable that the index number that we arrive at is invariant with the method of aggregation that we choose. No matter how we aggregate we must always arrive at a uniquely representative index. This desirability sometimes calls for very stringent restrictions on the model.

2.4.1.1 Definition of Index Number

What exactly is an index number? An index number may be defined in several ways depending on the purpose. Fisher (1967:3) suggested that the designing of index numbers is based on the need to represent, in a single number, divergent movements of quantities or prices of goods and services over time, space, individuals, or set of circumstances. In a way this is an aggregation problem.

Samuelson and Swamy (1974) discern three approaches to the theory of index numbers in the literature. These are:

(1) Index number as a measure of central tendency of a universe of price changes over time. This approach is associated with such early writers as Jevons and Edgeworth. If we observe prices (or quantities) beginning at any time from the same point, they will tend to move in different directions and by different magnitudes. The index number is the [general] resultant of the different movements.

(2) During the period following the first world war writers such as Irving Fisher, Walsh, and Palgrave, who, in the words of Samuelson and Swamy, "applied certain mechanical tests to index number formulas to define index numbers as averages or geometric means".

(3) The economic theory approach to index numbers, associated with such names as Marshall, Wicksel, Könus, Allen, Wold, Samuelson, Afriat, Theil, Fisher to mention but a few.

It is the economic theory approach that is of interest here. An economic price index is defined as the ratio of the minimum cost of a given level of living in two price situations. More formally, we can represent the economic price index as:

$$\begin{aligned} p[P^1,P^o|u(Q^a)] &\equiv p(P^1,P^o;Q^a) \\ &= \frac{e(P^1;Q^a)}{e(P^o;Q^a)} \\ &= \frac{e[P^1|u(Q^a)]}{e[P^o|u(Q^a)]} \end{aligned}$$

where $u(Q^a)$ is a given level of utility derived from the quantity Q^a and $e(P^i;Q^a)$ denotes the i-th expenditure function. By definition,

$$\begin{aligned} e(P^i;Q^a) &\equiv e[P^i|u(Q^a)] \\ &= \min_Q P^i.Q \\ s.t.\quad & u(Q)=u(Q^a). \end{aligned}$$

The e functions are linear homogeneous and concave in prices.

(b) An economic quantity index measures, for two presented quantity situations Q^o and Q^1 for a given price situation P^α, the ratio of minimum expenditure needed to buy their respective levels of well-being. Formally the quantity index can be represented as follows

$$q(Q^1,Q^o;P^\alpha)=\frac{e(P^\alpha;Q^1)}{e(P^\alpha;Q^o)}$$

where $e(P^\alpha;Q^1)$ and $e(P^\alpha;Q^o)$ are expenditure levels for quantity situations Q^1 and Q^o for a particular price situation P^α.

2.4.1.2 Index Numbers and Productivity

The Divisia Index and its derivatives as well as econometric methods are commonly used for technical change estimations. The underpinning of the Divisia index is its association of productivity growth or technical change with the time derivative of the production, cost or profit function. This association was demonstrated for the production function by Solow in a 1957 classic paper.

A divisia index can be defined as a mapping of a line integral into a real number line (Hulten, 1973). Suppose $X\equiv(x_{1t},x_{2t},\ldots,x_{Nt})$ is a set of observed quantities which are to be indexed and $(p_1,p_2\ldots,p_N)$ is the associated price vector. Let $\alpha_{(t)}$ denote the path of the **x**'s over time interval **[O,T]**. Then the Divisia index is defined as

$$D_\Gamma=\exp(\int_\Gamma(\sum_{i=1}^{N}\frac{p_{it}x_{it}}{\sum_{j=1}^{N}p_{jt}x_{jt}}\frac{\dot{x}_{it}}{x_{it}}) \tag{2.1}$$

where Γ is the curve described by α_t, $O\leq t\leq T$, and $\dot{x}_{it}=\frac{\partial x_{it}}{\partial t}$.

The Divisia index has many desirable properties[2], including (i) invariance, (ii) it can always be computed for given observations on prices and quantities, and (ii) it approaches the continuous form as the change in time tends to zero. However, the divisia index also suffers one major defect (Hulten, 1973), namely, the cycling problem. That is, since in general the line integrals are path dependent, $D_{\Gamma 1} \neq D_{\Gamma o}$. A line integral is said to be path independent if, in an open region S in R^n,

$$\int_{\Gamma_{(x,y)}} \varphi d\alpha = \int_{\Gamma_{1(x,y)}} \varphi d\beta$$

for φ continuous on S, and x and y are two points in S (Hulten, 1973:1018).

To avoid cycling the following assumptions are necessary:

(i) there exists an aggregate defined on S.

(ii) the aggregate is linear homogeneous.

(iii) there exists an observable price normal at each point in S, unique up to a scalar multiplication.

Unfortunately the Divisia index is moulded in terms of continuous time. Approximation of the Divisia index we be cognizant of the fact that data is available in but discrete form. The relevant form of the divisia index is derived from the Tornqvist approximation

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[2] For a detailed discussion of the properties of the divisia index see Richter (1966).

$$\log D_t - \log D_{t-1} = \sum_{i=1}^{N} \tfrac{1}{2}[S_{i,t} + S_{i,t-1}][\log x_{i,t} - \log x_{i,t-1}] \tag{2.2}$$

where $S_{i,t} = \frac{p_{i,t} x_{i,t}}{\sum_{j=1}^{N} p_{j,t} x_{j,t}}$ is the share of the i-th component in the t-th period. This

gives the rate of change of the discrete divisia index, since $\frac{\partial \log D_t}{\partial t} = \frac{1}{D_t}\frac{\partial D_t}{\partial t} \approx \frac{\Delta D_t}{D_t}$ as $\partial t \to 0$..

Solow's 1957 seminal paper crystallized awareness about the close relationship between index number equations and the underlying production, cost or profit function. In developing his technical change index Solow proceeds by making the assumption that the production function shows constant returns to scale. He also assumes that the technical change is neutral[3] and that perfect competition obtains in both the input and output markets. He then calculates technical change as a residual: that is, according to the neoclassical theory of production and distribution, under constant returns to scale and perfect competition, payment to all factors would exhaust output in the absence of technical

---

[3] Technical change is said to be Hicks neutral if the marginal rate of factor substitution between inputs is not affected by the change. Non-neutral technical change is biased, e.g. labour-saving (capital-using) if the marginal product if capital rises relative to the marginal product of labour, all other things constant.

change. Therefore, technical change is the difference between the rates of growth of output and all inputs.

A major criticism of the Divisia index is that it is presented in continuous time but can only be approximated using discrete data in which form economic data is available. Direct estimation with discrete data does not yield unique estimates of technical change or total factor productivity (e.g. Diewert, 1980). However, Divisia index number calculations of technical change require no specification of the functional form of the production or cost function.

The theory of duality in production analysis affords further opportunity for investigating factor productivity and/or technical change. The essence of the theory of duality is that the production technology can be completely characterized by either the production function or the cost or profit function. Intuitively- the transformation of inputs into output can be characterized by the production function which represents the maximum output obtainable from the various input vectors. Under certain regularity conditions[4] an equivalent representation of efficient production technology is provided by the cost or profit function. A cost function shows the minimum expenditure required to produce a given quantity of output and input prices while the profit function shows the

---

[4] These include the conditions that the production function must be continuous linear homogeneous and concave from below. See for example Shephard (1970), McFadden (1978), and Chambers (1988).

maximum profit available at given input and output prices.

The disadvantages of the dual cost function lie in its treatment of output as exogenous. In situations where the production function is not constant returns to scale this misspecification may introduce simultaneous equation biases in the estimators. In addition, the dual cost function essentially ignores the effects of output price on the firm's choice of input levels, making it somewhat an unrealistic approach to modelling economic behawiour. Lastly, the theory of cost minimization is based on the individual agent so that its application to aggregate data may be inappropriate, unless very restrictive conditions are placed on the distribution of output and income among the individual agents over whom data is aggregated. For example, the assumption that marginal costs for the individual farms are independent of the scale or size of the farm may be required to justify aggregation.

Diewert (1976) showed that for a certain class of functional forms, the Tornqvist approximation to the Divisia index is exact or, "superlative", for a unit cost function. His derivation assumes technology with constant returns to scale. He is able to relax the assumptions of neutral technical change and perfect competition, even though in cases of joint production perfect competition in output markets may still be necessary (Baltagi and Griffin, 1988). The assumption of cost minimization implies that Shephard's lemma is applicable. We present a sketch of Diewert's approach. Assume there exists a single output enterprise with a homothetic production function $y=f(x,t)$, we can write its translog cost function (introduced by Christensen, Jorgenson and Lau, 1971) thus

$$\begin{aligned} lnC(\omega,y,t) &= \alpha_o+\alpha_y lny+\tfrac{1}{2}\sum_{i=1}^{n}\alpha_{iy} lny \ln\omega_i \\ &+\alpha_{yt} t lny+\sum_{i=1}^{n}\alpha_i \ln\omega_i+\tfrac{1}{2}\sum_{i=1}^{n}\sum_{k=1}^{n}\alpha_{ij}\ln\omega_i\ln\omega_j \\ &+\sum_{i=1}^{n}\alpha_{it} t\ln\omega_i+\alpha_t t+\alpha_{tt}t^2 \end{aligned} \tag{2.3}$$

where ω_i $(i=1,...,n)$ is the price of the i-th input, y is the output level, and t is the trend variable that captures the changes in the production environment as time proceeds.

The derivation of the exact index number requires the following quadratic lemma (Diewert,1976). Let the function $g(z)=g(z_1,...,z_n)$ be quadratic and differentiable in z. Then

$$g(z_1)-g(z_o)=\tfrac{1}{2}\left[\frac{\partial g(z_1)}{\partial z}+\frac{\partial g(z_o)}{\partial z}\right]^T(z_1-z_o)$$

where $g(z)$ is evaluated at points 0,1. Since the translog cost function (2.3) is quadratic in logarithms, we have

$$
\begin{aligned}
lnC_1 - lnC_o = ½\sum_{i=1}^{n}\Big[\frac{\partial\, lnC_1}{\partial\omega_i} + \frac{\partial\, lnC_o}{\partial\omega_i}\Big]\ln\Big(\frac{\omega_i^1}{\omega_i^o}\Big) \\
+1/2\Big[\frac{\partial lnC_1}{\partial y} + \frac{\partial lnC_o}{\partial y}\Big]\ln\Big(\frac{y^1}{y^o}\Big) \\
+½\Big[\frac{\partial lnC_1}{\partial t} + \frac{\partial lnC_o}{\partial t}\Big](t_1 - t_0)
\end{aligned}
\qquad (2.4)
$$

Assuming competitive profit maximization implies marginal cost is equal to the price of the output (i.e $\frac{\partial C}{\partial y}=mc=p$). Together with Shephard's lemma ($\frac{\partial C}{\partial w_i}=x_i$) (2.4) yields

$$
\begin{aligned}
lnC_1 - lnC_o = ½\sum_{i=1}^{n}\Big[\frac{\omega_i^1 x_i^1}{C_1} + \frac{\omega_i^o x_i^o}{C_o}\Big]\ln\Big(\frac{\omega_i^1}{\omega_i^o}\Big) \\
+½\Big[\frac{p^1 y^1}{C_1} + \frac{p^o y^o}{C_o}\Big]\ln\Big(\frac{y^1}{y^o}\Big) \\
+½\Big[\frac{\partial lnC_1}{\partial t} + \frac{\partial lnC_o}{\partial t}\Big](t_1 - t_o)
\end{aligned}
\qquad (2.5)
$$

Now, suppose there is technical progress. It means we can obtain more maximal output from a given bundle of inputs. In terms of the cost function it implies more output from the same cost level or, equivalently, same output at less cost. That is, the isocost curves shift outward (see Figure 2.2). Let the impact effect on cost due to technical change at time *t* be denoted as $\Gamma \equiv \partial \ln C(w,y,t)/\partial t$. This is the percentage change in cost at time t that cannot be explained by changes in output

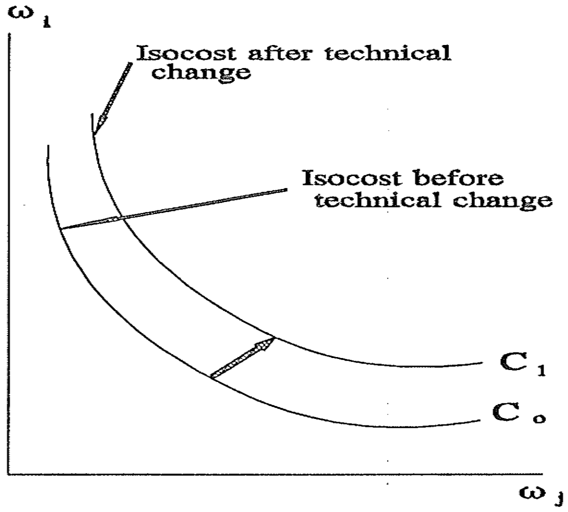

Figure 2.2 Before and After Technical Progress Isocosts

quantities or input prices. Since with technical progress we obtain more output from the same bundle of inputs we should normally expect Γ to be negative. Substituting Γ in equation (2.5) and solving for it we obtain the identity

$$\tfrac{1}{2}[\Gamma_1+\Gamma_0](t_1-t_o)=[lnC_1-lnC_o]-\tfrac{1}{2}\sum_{i=1}^{n}[\frac{\omega_i^1 x_i^1}{C_1}+\frac{\omega_i^o x_i^o}{C_o}]\ln(\frac{\omega_i^1}{\omega_i^o}) \\ -\tfrac{1}{2}\sum_{j=1}^{m}[\frac{y_j^1 p_j^1}{C_1}+\frac{y_j^o p_j^o}{C_o}]\ln(\frac{y_j^1}{y_j^o}) \tag{2.6}$$

This can be interpreted as the average percentage change (reduction) in cost due to technical change between the time periods t_o and t_1. As mentioned earlier, $\tfrac{1}{2}[\Gamma_1+\Gamma_o](t_1-t_o)<0$ implies there was technical progress during this time period.

However, if the technology is not translog (or, in cross-sectional analyses, the second-order parameters differ across the economic units), the Tornqvist approximation can result in considerable distortion. This is the problem Denny and Fuss (1982) address. Starting from Taylor's series expansions about two points to be compared, they develop a general growth accounting equation which can be approximated to any desired degree of accuracy, depending on the information available. Under this approach, the quadratic lemma, which forms the bedrock of superlative index numbers, is but a special case. Denny and Fuss are then able to calculate the bias of the index number comparisons when the assumptions of constant returns to scale and perfectly competitive markets are violated.

2.4.1.3 Problems with Index Numbers

The method of index numbers in general is not without criticisms. Some of the problems with index numbers include:

(i) Arbitrariness

(ii) Choice of weighting mechanism

(iii) Choice of base period, that is, chain link methods versus non-chain linking methods

(iv) Choice of index number formula.

2.4.2 Econometric Approach

Econometric estimation allows us to investigate directly the changes in the structure of the production technology. For example, factor substitution can be analyzed in a relatively straightforward manner. Changes in relative factor abundance will affect the relative factor prices. Assuming cost minimization, producers will substitute away from the more expensive factor(s) to the cheaper one(s).

Most early econometric studies assumed that technical change is disembodied and progresses in step with time. In such a framework incorporation of technical change was achieved by inclusion of a linear time trend in the model. The translog functional form (Christensen, Jorgenson, and Lau, 1971) and other flexible forms (e.g. quadratic and generalized Leontief, due Diewert, 1974) have allowed for interaction between time (technology) and prices and quantities. Attempts to estimate elasticities of substitution using the translog dual cost function have assumed constant returns to scale and either Hicks-neutral or factor-augmenting (biased) technical change. For instance, Binswanger (1974) assumed factor-augmenting technical change and found evidence of biased technical change and no support for land saving innovations in a five-input translog cost function model of the U.S. agricultural sector. Berndt and Wood (1975), using a constant returns to scale four-input translog cost function could not reject the hypothesis of Hicks-neutral technical change in the aggregate US manufacturing sector. This was in accord with Solow's (1957) findings using an aggregate production in a nonparametric framework on US data for the period 1909-1949. Lopez (1980) using a Generalized Leontief specification of the cost function found no evidence of factor-augmenting technical change in Canadian Agriculture. Berndt and Christensen (1973) using US manufacturing data for the period 1929-1968 applied the translog specification for the production function. Assuming Hicks-neutral technical change and weakly separable production function, they report evidence of better possibilities of substituting structures for labour than equipment for labour.

Some more recent studies have attempted to investigate multifactor productivity growth using more general formulations. Denny and Fuss (1982) develop a general second-order accounting equation which includes intertemporal and interspatial effects as well as second-order and interaction effects. This requires structural estimation before evaluation. They apply this framework to compare productivity gains between U.S. and Japanese private economies and evaluate the relative cost efficiencies of regional total manufacturing in Canada. They are able to correct for biases in the tornqvist index numbers arising from violation of the assumption that the second-order parameters are constant.

Baltagi and Griffin (1988) in an effort to "break out of the quadratic straightjacket" embodied in the second-order flexible functional forms, propose yet another general index of technical change. By incorporating a general index of technical change in a translog specification they are able to decompose estimates of total factor productivity into technical change and scale effects.

2.4.3 Other Approaches

There are other approaches to measuring total factor productivity. These include nonparametric calculations. Farrell (1957) provided a pioneering framework for definitions and computations of both allocative and technical efficiency in a nonparametric framework. Assume a firm's production technology can be characterized by $y=f(x_1,x_2)$ which is constant returns to scale, that is, the frontier technology can be characterized by the unit isoquant **UU'** in Figure 2.2 below.

Let the point A represent $(\frac{X^o_1}{y^o},\frac{X^o_2}{y^o})$. The ratio $\frac{OB}{OA}$ measures technical efficiency; it is the ratio of inputs needed to produce y^o to the inputs actually used to produce y^o, given the input mix used. If **PP'** represents the relative input prices, then the ratio $\frac{OD}{OB}$ measures allocative inefficiency since the cost of point **D** is the same as that of the

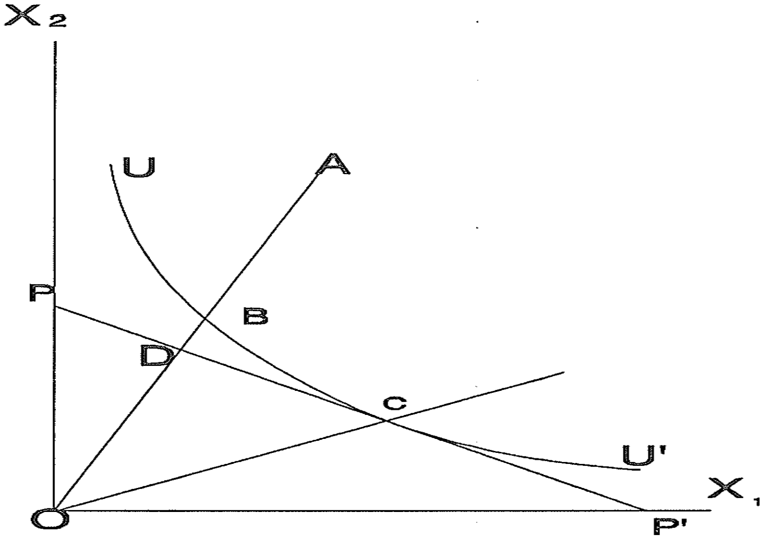

Figure 2.3 Farrell Allocative and Technical Efficiencies

allocative efficient point **C**, and is less than that of the technically efficient but allocatively inefficient **B**. Finally $\frac{OD}{OA}$ measures total efficiency.

Since the efficient unit isoquant **UU'** is not observable it must be estimated from a sample of possibly inefficient observations like **A** (Farrell, 1957:255) with the rest of observations lying above it. One disadvantage of this methodology is apparent, namely, that the frontier is computed from a subset of observations and is therefore susceptible to outlier observations and measurement errors. The restrictive constant returns to scale assumption is another shortcoming of this approach. Advantages lie in the fact the methodology is parameter free. That is, no parametric functional form is specified and thus imposes fewer or no structural restrictions (Byrnes, Färe, Grosskopf and Kraft, 1987:368). Further, it is possible to specify a multiple output, multiple input technology.

Many studies on changes in productivity have used the nonparametric method pioneered by Farrell. Byrnes, Färe and Grosskopf (1984) apply a generalized version of the Farrell measure to discern pure technical efficiency, input congestion and overutilization of some inputs, and scale effects for a sample of Illinois strip mines. Weersink, Turvey and Godah (1990) compute technical efficiency and also decomposed it into purely technical, congestion and scale efficiency measures. Chavas and Cox (1990) developed a nonparametric framework for analyzing technical change under profit maximization and a 'generalized augmentation' hypothesis and apply it to US agriculture. Kopp (1981) surveys the literature on efficiency measures.

2.5 Analytical Models

Before proceeding further we note the following about the production environment:

(i) During the period under study most prices (for both inputs and outputs) were administered (fixed) by relevant government bureaus on a cost-plus basis. Government agencies held monopoly power for distributing inputs and purchasing of produce. Notwithstanding the influence the different farmer groups have on the price setting process, these prices are practically exogenous to the individual producers. Output is also exogenous to the extent that production involves biological processes over which producers have but partial influence.

(ii) Though not necessarily always joint-production, agricultural activities are characterized by multiple outputs. However, input-output separability is assumed in order to be able to estimate an aggregate cost function.

(iii) Advance announcement of the prices considerably reduces the price risk. In our case prices were announced before farmers completed their planning for the following season.

(iv) Producers could sell all their produce at the ruling prices to some government agency.

2.5.1 Some Basic Assumptions

In order to develop our analytical models we typically assume that there exists an aggregate production function. By duality the existence of an aggregate production function implies the existence of a corresponding cost function (e.g. Shephard, 1970; Chambers, 1988), under the regular optimization assumptions.

Let us adopt the definition of change in multifactor productivity as any shift in the aggregate production function. We can then calculate it as the residual after accounting for all quantifiable variables. In essence this separates movement of the production function from movement along the production function. This is consistent with the fact that both quantity and quality of the inputs and outputs change over time. In other words, movement of the production function may be accompanied by movement along the production function (Capalbo, 1988:54).

In the framework of the cost function, improvement in the total factor productivity is characterized by reduction in the cost of production that cannot be explained by changes in output quantities or input prices. By definition a cost function is the minimum cost of producing a given output level during a given time period expressed as a function of input prices and output quantities.

Consider a firm that is price-taking in input markets. Assume that in a single period output and one of the inputs are fixed. Further assume that the firm minimizes variable costs subject to the fixed output level, a production function constraint, and fixed factor limitations. This variable cost function can be represented as

$$C_t \equiv C(\omega_t, y_t, k_t, t) = \min_x \{\omega \cdot x : (x, y, \kappa) \in S^t, \quad \omega > 0\} \tag{2.7}$$

where $x=(x_{1t},\ldots,x_{nt})$ is the vector of the inputs and $\omega=(\omega_{1t},\ldots,\omega_{nt})$ is the $(1xn)$ vector of the corresponding input prices; $y_t=(y_{1t},y_{2t},\ldots,y_{mt})$ is the $(1xm)$ output vector while k denotes the vector of quasi-fixed inputs. S^t is a closed nonnegative feasible set of input-output combinations. t is the trend variable that proxies technology or changes in the production environment as time proceeds. The subscript t denotes the t-th period. $C(\omega, y, K, t)$ (the t subscripts are dropped to ease notation) has the following usual properties:

(1) $C(\omega,y,k,t) \geq 0$ for $\omega > 0$, and $y>0$, k, and t fixed. That is, C(.) is real-valued, nonnegative for all positive prices ω.

(2) Continuous and concave in ω and in y.

(3) Positively linear homogeneous in ω for fixed (y,k,t).

(4) Nondecreasing in ω; y, k, t fixed. i.e. if $\omega^1 \geq \omega$, then $C(\omega^1,y,k,t) \geq C(\omega,y,k,t)$.

(5) Monotonically nondecreasing in y, for fixed (w,k,t); i.e. if $y^1 \geq y$, then $C(\omega,y^1,k,t) \geq C(\omega,y,k,t)$. It tends to infinity as y tends to infinity.

(6) $C=C(\omega,y,k,t)$ is twice differentiable in input prices. Under this property $C=C(\omega,y,k,t)$ has the following important derivative property (also known as Shephard's lemma): $\frac{\partial C(\omega,y,k,t)}{\partial \omega_i}=x_i$. It follows, therefore, that

$$\frac{\partial^2 C(\omega,y,k,t)}{\partial \omega_i \partial \omega_j}=\frac{\partial^2 C(\omega,y,k,t)}{\partial \omega_j \partial \omega_i}.$$

These symmetry conditions are important for conserving degrees of freedom in applied econometrics

2.5.2 Index Number Model

Assuming competitive cost minimizing behaviour, a translog cost function for a multiple output enterprise and an aggregate production function ($F(Y,X,k,t)=0$) can be specified as

$$\begin{aligned} lnC(\omega,y,K,t) &= \alpha_o+\sum_{j=1}^{m}\alpha_j lny_j+½\sum_{i=1}^{m}\sum_{j=1}^{m}\alpha_{ij}lny_i lny_j \\ &+½\sum_{i=1}^{n}\sum_{j=1}^{m}\alpha_{ij}lny_j\ln\omega_i+\sum_{j=1}^{m}\alpha_{\kappa j}\ln\kappa lny_j+\sum_{j=1}^{m}\alpha_{jt}tlny_j \\ &+½\sum_{i=1}^{n}\sum\alpha_{ij}\ln\omega_i\ln\omega_j\sum_{i=1}^{n}\alpha_i\ \ln\omega_i+\sum_{i=1}^{n}\alpha_{ik}\ln\kappa\ \ln\omega_i \\ &+\sum_{i=1}^{n}\alpha_{it}t\ln\omega_i+\alpha_\kappa\ln\kappa+\alpha_{kk}\ln\kappa^2+\alpha_{tk}t\ln\kappa+\alpha_t t+\alpha_{tt}t^2 \end{aligned} \tag{2.8}$$

(**2.8**) is quadratic in logarithms. Applying the quadratic lemma (Diewert, 1976), and assuming competitive profit maximization (therefore relaxing the constant returns to scale restriction) implies marginal cost is equal to the price of the output, (i.e $\partial C/\partial y=\mathbf{p}$), and $\mathbf{r^k=\partial lnc(w,y,k,t)/\partial lnk}$ is the shadow price of k. Together with Shephard's lemma results in

$$
\begin{aligned}
lnC_1-lnC_o={}&½\sum_{i=1}^{n}[\frac{\omega^1_i x^1_i}{C_1}+\frac{\omega^o_i x^o_i}{C_o}]\ln(\frac{\omega^1_i}{\omega^o_i})\\
&+½\sum_{j=1}^{m}[\frac{p^1_j y^1_j}{C_1}+\frac{p^o_j y^o_j}{C_o}]\ln(\frac{y^1_j}{y^o_j})\\
&+½[\frac{r^k_1\kappa_1}{C_1}+\frac{r^k_o\kappa_o}{C_o}]\ln(\frac{k^1}{k^o})\\
&+½[\frac{\partial lnC_1}{\partial t}+\frac{\partial lnC_o}{\partial t}](t_1-t_0)
\end{aligned}
\qquad (2.9)
$$

Improvement in total factor productivity implies that more maximal output can be obtained from the same bundle of inputs. In terms of the cost function it implies that it costs less to produce a given quantity of output. That is, the isocost curves shift outward (Figure 2.2).

Define this impact effect on cost due to improved TFP at time *t* as $\Gamma\equiv\partial\mathbf{lnc(w,y,t)}/\partial\mathbf{t}$. This is the percentage change in cost at time *t* that cannot be explained by changes in inputs or output prices and quantities. Since with higher MFP we obtain more output from the same bundle of inputs we should normally expect Γ to be negative. Substituting Γ in (**2.9**) and solving for it gives the identity

$$
\begin{aligned}
\tfrac{1}{2}[\Gamma_1+\Gamma_0]=[lnC_1-lnC_o]&-\tfrac{1}{2}\sum_{i=1}^{n}[\frac{\omega_i^1x_i^1}{C_1}+\frac{\omega_i^ox_i^o}{C_o}]\ln(\frac{\omega_i^1}{\omega_i^o})\\
&-\tfrac{1}{2}\sum_{j=1}^{m}[\frac{y_j^1p_j^1}{C_1}+\frac{y_j^op_j^o}{C_o}]\ln(\frac{y_j^1}{y_j^o})\\
&-\tfrac{1}{2}[\frac{r_k^1k^1}{C_1}+\frac{r_k^ok^o}{C_o}]\ln(\frac{k^1}{k^o})
\end{aligned}
\tag{2.10}
$$

This can be interpreted as the average percentage change (reduction) in cost due to improved total factor productivity between the time periods t_o and t_1. As mentioned earlier, $\tfrac{1}{2}[\Gamma_1+\Gamma_o](t_1-t_o)<0$ implies there was technical progress during this time period. This is the equation used for empirical implementation of the tornqvist divisia indexing methodology.

2.5.3 Econometric Model

Econometric implementation requires specification of a functional form of the structure for the technology of production. Several functional forms are possible candidates. Basically the chosen functional form must be consistent with the objective of the analysis. In addition it must possess the following qualities (Fuss, McFadden, & Mundlak, 1978:224-225):

(i) Relatively easy to implement. Statistical theory is much more well developed for linear-in-parameters functional forms than for non-linear forms.

(ii) Interpretation of results should be reasonably easy. Parameters should have an intrinsic and intuitive economic interpretation. Functional forms that may be rich in parameters but that involve complex transformations may contain implausible and sometimes not so obvious implications.

(iii) Few *a priori* restrictions on the parameters. For example, it is not necessary to *a priori* restrict the elasticity of substitution to unity (e.g. the Cobb-Douglas) or for that matter to any constant (like the CES does). It is conceivable that such measures depend on the data. This means that they can vary across the sample and need not be parametric. As a result, we can obtain more parameters that portray as many relevant economic effects as possible. However, the form of choice is still expected to be niggard in parameters. It must contain no more parameters than are necessary for consistency with the maintained hypotheses. In small samples excess parameters result in a loss of degrees of freedom.

Several functional forms meet the above requirements to varying degrees. In this study we choose the translog cost function mainly because in addition it is flexible. That is, it can approximate to the second degree an arbitrary cost function. We specify a single output-two variable factor variable translog cost function with two quasi-fixed inputs. For this purpose **(2.8)** is modified to incorporate the cost-impact of farmsize (in hectares, h), number of farmers (f) and rainfall, R. That is, $C=C(\omega, Y, K, R, h, t)$.

Assuming that technical change (or total factor productivity) is cost-neutral we can define the shift in the cost function over time as technical change. This is equivalent to the partial derivative of the cost function with respect to time. That is

$$\Gamma(\omega,\ Y,\ K,\ h,\ R,\ t) \equiv \frac{\partial lnC(\omega,\ Y,\ K,\ h,\ R,\ t)}{\partial t}$$
$$= \alpha_t + \alpha_{yt} lnY + \alpha_{kt}\ lnK + \alpha_{rt}\ lnR$$
$$+ \alpha_{ht} lnh + \sum_{i=1}^{n} \alpha_{ti}\ \ln\omega_i.$$

Direct estimation of $\Gamma(\omega, Y, K, h, R, t)$ is not possible because the left hand side is not observable. Therefore the full structure of the technology is estimated using a three-equation systems technique:

$$\begin{aligned} &(1)\quad C = C(\omega, y, k, R, h, t) \\ &(2)\quad S_L = \frac{\partial\, lnC}{\partial \ln\omega_L} = \frac{\omega_L X_L}{C} \\ &(3)\quad S_R = \frac{\partial \ln C}{\partial \ln p} = \frac{pY}{C} \end{aligned} \qquad (2.11)$$

where S_L, S_R are labour and revenue shares respectively.

Chapter 3

The Data

Chapter 2 discussed the theoretical foundations of the method of analysis and presented the analytical models. This chapter takes up the question of the data. A synoptic description of the data used in this study is presented.

3.1 Sources

In principle once we have decided upon the model determination of the types of data is pretty straightforward. In practice we are often constrained by the bounds of availability and the quality of the data.

Price and quantity data on inputs and outputs and investment expenditures were obtained from various publications of the Central Statistical Office (CSO) and Ministry of Agriculture. These were supplemented by data obtained from various sources including the Commercial Farmers Bureau, the International Monetary Fund and World Bank publications. Information on amount of land operated was obtained from various CSO publications.

3.2 Scope

Data availability limits the empirical analysis to the commercial farming sector. The definition of a commercial farmer varies depending on the purpose(s). This study adopts the definition by Central Statistics Office (CSO) because it is more general. According to CSO[5], a commercial farmer is one who meets at least one of the following

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[5] Central Statistics Office, *Agricultural and Pastoral Production:Commercial Farms;* an annual publications 1977/78 to 1986/87.

criteria in respect of the agricultural activity during the year, ending September 30:

(a) Any farmer who sold during the last 12 months to the National Agricultural Marketing Board (NAMBoard) or any Co-operative union any such crops the value of which was equivalent to 150x90kg bags of maize or more at the ruling producer price for maize.

(b) Any farmer who grew tobacco in his own name and was registered with the National Tobacco Company of Zambia Limited.

(c) Any farmer who sold to the Dairy Produce Board.

(d) Any farmer who bred, reared and/or fattened cattle or poultry and sold them to the Cold Storage Corporation of Zambia, Poultry Processing Company Ltd or to any licensed butcher or supermarkets.

(e) Any farmer who reared and/or fattened pigs and sold them to the Zambia Pork Products or to the Cold Storage Corporation of Zambia or to any Licensed butcher or supermarket.

(f) All hybrid poultry breeders.

(g) All state farms operated by the Agricultural Division of the Zambia Industrial and Mining Corporation (ZIMCO) and other agencies on commercial basis.

Data were available for ten years (1978-87). Farmers were grouped based on the hectarage that they operated. A cursory preview of the rest of the data is presented.

3.3 Variable Costs

Variable costs are defined in this study as labour and fertilizer quantities multiplied by the respective prices, in 1978 prices. Limiting the definition of variable costs to these two items is a result of lack of data on unit prices or quantities of several variable inputs (e.g. fuels and lubricants, electricity, water, veterinary medicines).

3.4 Labour

This includes salaried and piece-rated (or part time) farm workers and family labour. Annual data on numbers employed and the expenditures were obtained. The wage rate is calculated simply as expenditure per farm worker per year. Because farmers generally keep an eye on expenditures on this item one generally expects data on this variable to be reliable. However, no information was available regarding payments-in-kind and the cost of providing housing. Many commercial farmers provide housing on their farms for the permanent workers. On the contrary, payment-in-kind is common among smaller farmers.

During the one year periods that we consider we assume that the farmer can freely hire and fire workers at any time. That is, labour is a variable input. Further, the labour market is assumed to be competitive (or quite competitive) so that the wage rate is exogenous to the farmers and marginal cost pricing applies. This particular assumption does not seem far fetched. Quite often farm workers have the option of going back to the land and, for example, get into subsistence farming. Therefore, farm wages relative to non-farm income are important in labour supply decisions.

Family labour is the labour supplied by the family members. The main difference between hired and family labour is that the latter is not paid a salary or wage. Nonetheless, this labour is a very important input in agriculture. For some categories of producers in Zambia there are as many unpaid family workers as there are paid farm workers. The issue then becomes how to value family labour. Ideally we cost all allowances and living expenses on the family. But lack of information on this item forces one to typically impute family labour costs.

The traditional (or common) approach to costing family labour is assume that the marginal product of family labour is the same as that of salaried labour. Assuming perfect competition in the labour market implies that labour is paid according to the value of its marginal product. Hence family labour will also be valued at the same wage rate as hired labour. Valuing family labour and hired labour at the same ruling wage rate permits their aggregation into a single homogeneous input, labour[6].

The next question is whether family labour is variable or quasi-fixed. Common sense suggests that it is less variable than hired labour, especially in a one year interval. However, for the purpose of this study it is treated as a variable input because no data was available on expenditures on family labour. Only physical quantities of family labour were available. This could not permit calculation of the unit price for family labour.

3.5 Capital

This is a very complex variable. First we note the characteristic of heterogeneity: tractors and trailers, disc ploughs, seeders, sprayers, trucks and cars, buildings and other constructions, plantation development, irrigation equipment, water pumps, breeding livestock and poultry, human capital, etc.

Heterogeneity and complexity notwithstanding, the use of the capital variable requires aggregation of the different component assets. Aggregation and measurement of

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[6] Under price proportionality exact aggregation is possible. See e.g. Diewert, 1980.

capital has both conceptual and practical problems[7]. Depending on how capital is measured the productivity indexes obtained will vary[8]. Several methods exist for estimating stocks of capital, depending on the purpose and resources available[9].

The major differences among the approaches to measuring capital stocks stem from the assumptions about the path of physical deterioration of the assets. In one common approach, the "one-hoss shay", deterioration is based on the assumption that once an asset is put into place, it provides the same amount of services during each period until it expires. A practical problem with this approach is that the time at which the durable goods expire is stochastic, it varies among types of the assets and individual assets.

An attractive decay pattern is the constant exponential specification. This is based on the assumption that the rate of [physical] deterioration is constant and equal to some $\delta\%$ per time period. Aggregate capital stock at the end of period t based on the constant exponential deterioration is computed as

$$K_t = \sum_{s=0}^{T} \phi_s I_{t-s} \qquad \textbf{(3.1)}$$

where K_t is the stock of capital in period t, I_t is gross investments during the period, and $\boldsymbol{\phi_s = (1-\delta)^s}$

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[7] Diewert (1980) gives a quite exhaustive discussion on problems in the measurement of capital. These include:

[8] Bureau of Labour Statistics, USDL; *Productivity: A Selected Annoted Bibliography. 1971-75*

[9] D. Usher (1980, p3) identifies five purposes, namely; investment function, consumption function, production function, budgeting and planning, and national accounts purposes; and at least three approaches to measuring capital stocks -perpetual inventory method, book value of firms of insurance records, and direct surveys.

is the geometric economic depreciation of capital with δ is the one period rate of depreciation, and s is the age, in years, of the capital asset.

In this study capital stocks for each period are generated using the perpetual inventory method. This is a weighted sum of past gross investment streams, just another way of writing the net capital stock equation[10].

The perpetual inventory method recognizes the fact that plant and equipment are long-lived, durable goods. Investment outlays that renew and expand the stock plant and equipment increase potential capacity output supply both in the present period and in the future. In addition, new investment goods embody the most recent technical advancement so that potential benefits from such technical progress can be realized only as investment occurs. Consequently, variations in investment expenditures have long-term impacts on productive capacity (Berndt, 1990:225-228). Another advantage of the PIM is that it utilizes already available annual data on investment expenditures. This is basically because the concepts and the data used are mostly compatible with the national accounts. The PIM is also flexible. Certain variables and/or assumptions can be included or excluded from the model and it is possible to test its sensitivity to varying definitions and hypotheses (OECD, 1976:33-34).

This method is not without shortcomings. Notably there are valuation issues stemming from problems faced with aggregating capital[11]. For example, investment figures refer to outlays in the acquisition of new and used capital goods while prices

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[10] See e.g. Hulton and Wykoff, 1980,pp99-104.

[11] See Diewert, 1980.

sometimes are only for new assets. Another example is the implicit or explicit assumption that the termination value of a capital good is zero: it could even be negative (OECD, 1976:34). Definitional rigidities is another drawback of the PIM. As a result inadequate allowance is made for the effect of repairs and maintenance on the life and physical capacity of an asset.

The precision of the perpetual inventory method estimates depends basically on the assumptions about the average economic lifespans and the associated retirement of the different [types of] capital assets. In this study gross investments include net capital formation and depreciation charges. Net capital formation is defined as capital expenses less capital sales. Gross investment also includes such items as expenditures on additional land, farm residential buildings, nonresidential farm buildings, fencing and construction, land improvements, plantation development, and breeding livestock and poultry[12].

Calculation of capital stocks using the PIM is a three step process. First, determine the benchmark stocks. Second, select the depreciation pattern and the rate of depreciation. Third, calculate the stocks by **(3.1)**.

3.5.1 Benchmark Stocks

The first step in using the Perpetual Inventory Method is determination of stocks of capital at the beginning of the period under study. In this study it is assumed that

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[12] It was not possible to obtain information on investment in the education of family members.

Table 3.1 Benchmark Capital Stocks, Different Rates of Depreciation (1978 prices)

Depreciation(%)[§]	**8.00**	**10.00**	**13.00**
Farm Size Range	**Benchmark**	**Capital Stocks**	(in 1978 Kwacha)
0-79 ha	10278010.62	13227661.72	10964656.49
80-199 ha	9129809.95	11749942.87	9739747.67
200-399 ha	6406512.76	8245095.94	6834514.42
400-799 ha	46136141.98	59376595.50	49218371.86
800-1999 ha	57846251.30	74447349.02	61710801.66
2000+ ha	79511567.33	102330319.96	84823518.39

[§] Depreciaton is calculated as twice the reciprocal of the aggregate economic life of capital.

investment grew at an annual rate of 4% for thirty years prior to 1978[13]. Implicitly it is assumed that capital assets have an average life of twenty five years.

Deflating the 1978 gross investments by 1.04 gives an estimate of the 1977 investment level. By repeating this procedure we generate estimates for the years before that. Assuming the lifespan of the capital to average 30 years investment levels are calculated for that many years. The benchmark stocks are calculated using the perpetual inventory method. The results are presented in Table (3,1) for different assumptions about the average economic!lives (therefore depreciation rates) of the capital assets.

3.5.2 Shadow price of capital

In Zambia there are no well-developed rental markets for capital inputs. Firms typically purchase capital inputs and consume them entirely by themselves. This is

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[13] The 4 percent is based on growth estimates of the agricultural sector in those years. See, for example, NCDP, 1989:i.

especially true for commercial farmers who are suspected of being too mechanized (Krenz, et al, 1987). However, whether or not commercial farmers are actually over mechanized is essentially an empirical question.

The absence of market data on user cost of capital implies that one must typically infer indirectly the rental price of capital that firms implicitly charge themselves for their own capital inputs. A number of methods exist for estimating shadow prices of capital, depending on the assumptions made about the market:

1. Hall and Jorgenson (1967) stress the need for the rental price of capital to incorporate at least the following four effects: (i) the opportunity cost of the investment outlays; (ii) depreciation (iii) changes in the asset price of capital due to capital gains; and (iv) the effect of the relevant taxes. The user cost of capital is then calculated as $c_t = p_t(r_t + \delta - \frac{\Delta p_t}{p_t})$ where p_t is the asset price of the capital item in period t, r_t is the one-period interest rate yield in period t, δ is the one period constant depreciation rate and $\frac{\Delta p_t}{p_t}$ is the change in the asset price due to capital gains. Incorporation of the effect of the various taxes into this formula depends on the particular statutory provisions of the relevant tax laws[14]. This approach demands lots of data. For this study data the individual asset prices, capital gains and the impact of the relevant taxes could not be obtained. This

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[14] See also Berndt, 1990, p225 for more on this approach.

precluded its implementation.

2. In this study we adopt the approach of residual returns to capital. Consider the variable cost function

$$C \equiv C(\omega, y, \kappa, t) = \omega x \tag{3.2}$$

where k is a vector of quasi-fixed inputs, including land, and x is the vector of variable inputs. Assume short-run competitive profit maximizing behaviour and constant returns to scale. This implies that C is linear homogeneous in (y,k). For a single quasi-fixed input k we can calculate (by Euler's theorem and profit maximization) the unobserved shadow price of capital as

$$\frac{\partial C(\omega, y, k, t)}{\partial k} = \frac{(C - \sum_{j=1}^{M} p_j y_j)}{k} \quad (\leq 0) \tag{3.3}$$

A limitation of the index number calculations in this study is that, due to the absence of data on land values, the measure k of aggregate capital excludes land. Thus the magnitude of the shadow price of capital plus land under constant returns to scale in all inputs is overestimated when k excludes land in application of (3.3). However, this does not imply biases in calculations of the product $(\partial C(.)/\partial k) \cdot K$ (see 3.3). In turn $(\partial C(.)/\partial k) \cdot \Delta K$ is correctly measured within the Tornqvist formula (2.10) for technical change if the change in quasi-fixed inputs consists primarily of capital inputs rather than land. Thus the Tornqvist indexes are calculated over time within given farm size groups as measured by acreage, in an effort to reduce errors in application of (3.3).

Table (3,2) Shadow Price of Capital (*-(C-pY)/K*), by Farm Size in 1978 kwacha.

Farmsize (ha)	0-79	80-199	200-399	400-799	800-1999	2000+
1978	0.34	0.32	0.05	0.05	0.23	0.22
1979	0.25	0.14	0.04	0.04	0.05	-0.01
1980	0.10	0.08	0.08	0.06	0.13	-0.05
1981	0.20	0.18	-0.09	0.05	0.27	0.11
1982	0.15	0.11	0.08	0.03	0.26	0.08
1983	0.18	0.24	0.08	0.03	0.22	0.12
1984	0.24	0.21	0.09	0.02	0.19	0.04
1985	0.13	0.19	0.21	0.05	0.18	0.09
1986	0.32	0.02	0.13	0.018	0.40	0.06
1987	0.30	0.20	0.03	-0.15	0.31	0.08
Average	0.22	0.17	0.07	0.04	0.22	0.08

The negative of **(3.3)** can be interpreted as the potential reduction in variable cost from having an additional unit of capital. That is, under constant returns to scale and perfect competition, after payments to all variable factors have been made returns to the firm can be attributed to the fixed input. A negative shadow price implies that an additional unit of capital increases variable costs. In this study calculations of the shadow price of capital indicate that farmers actually lost money in some years (see Table 3.2) for each additional unit of aggregate capital they held. This may be a sign of over mechanization. On the other hand this reflects the quality of the data. For example, there are indications that the output is underestimated. This is especially likely for own consumption.

3.6 Intermediate Inputs

Commercial farmers are big consumers of purchased inputs and other intermediate materials. Quantity and price data were available only for fertilizers and manures. No such information was found concerning quantities and prices of feedstock and pesticides. Therefore, these expenditures were excluded in the total variable costs.

3.7 Other Inputs

3.7.1 Land: Land operated was measured in hectares. It included land put to crops and pastures (natural and non-natural), fallow land and land leased or rented from others during the year.

3.7.2 Rainfall: Rainfall for the period December-February is considered crucial for crop production as well as for the regeneration of the natural pastures which are important for livestock production. The Data used were national averages for these months and are not specific to farm size. Their incorporation in econometric estimations assumes equal distribution among farms.

3.8 Outputs

In this study output is defined as marketed quantities and quantities consumed by the farm households.

3.8.1 Crops: Eight crops are included, accounting for more than 80% of the total value of crops produced. These are: maize, seedmaize, tobacco, seedcotton, sunflowers, wheat, soybeans,and potatoes.

3.8.2 Livestock: The livestock and livestock products included are: beef and dairy cattle, milk, hogs (pigs), eggs, broilers and cockerels. Data on day-old chicks were not broken down according to the farmer categories.

Chapter 4

Empirical Results

Two techniques were adopted for empirical implementation in an effort to mitigate the effect of poor quality of the data; namely, the divisia indexing method to measure the changes in the multifactor productivity for the different farm sizes, and econometrics, by which we estimate magnitudes of the changes in cost as time proceeds and we attempt to explain the sources of the changes [if any] in the cost structure.

4.1 Tornqvist Index Numbers

The empirical implementation of the divisia indexes was achieved using tornqvist approximations, **(2.10)**. This equation essentially means that total factor productivity can be measured by the cost diminution that cannot be accounted for by changes in factor prices and quantities of outputs and the fixed inputs. The second term on the right in the first line is the tornqvist approximation to the divisia price index for inputs. The tornqvist output quantity index appears in the second line while the third line is the index of capital stocks. The tornqvist index numbers are chain-linked so that t_1-t_o=1).

Intuition tells us that an increase in productivity implies that a larger amount of output is obtained from the same quantity of inputs. This means that there is a reduction in cost of production. Therefore, the residual of **(2.10)** is normally expected to be negative, i.e. $1/2\,[\Gamma_1+\Gamma_o]\leq 0$. These residuals are shown in Table 4.1 and Figure 4.1 is a graphical presentation.

Table 4.1 Tornqvist Index Numbers of MultiFactor Productivity

ha (Av.)	0-79 (32.56)	80-199 (120.74)	200-399 (275.97)	400-799 (577.80)	800-1999 (1284.00)	2000+ (6099.15)
1979	-0.78	-0.44	-0.48	-0.41	0.49	0.41
1980	0.65	-0.65	-0.87	-0.39	-0.49	-0.09
1981	-0.32	-0.79	0.38	-0.63	-0.94	-0.53
1982	-0.36	-0.69	-0.70	-0.06	-0.65	-0.06
1983	-0.66	-0.08	-0.48	-0.25	-0.39	-0.28
1984	-0.38	-0.97	-0.56	-0.72	-0.53	-0.41
1985	-0.48	-0.25	-0.99	-0.22	-0.85	-0.55
1986	-0.60	-0.70	-0.98	-0.80	-0.11	-0.02
1987	-0.31	-0.42	-0.40	0.40	-0.25	-0.25
Ave.	-0.36	-0.56	-0.56	-0.34	-0.41	-0.20

Results of the tornqvist calculations suggest that productivity improved in general for all farmers (Table 4.1). During this period productivity improved for farmers operating up to 79 hectares, except for the year 1980 when it declined 65 percent from the previous year's level. On average productivity rose 36 percent per year for these farmers. Those farmers operating between 80 and 199 hectares saw their productivity rise at an average of 56 percent per year. The group of farmers working between 200 and 399 hectares performed very well during this period. Except for 1981 when productivity fell 38 percent over the previous year's level, these farmers had productivity advancement of between 40 and 98 percent. On average productivity improved 56 percent annually for this group of producers.

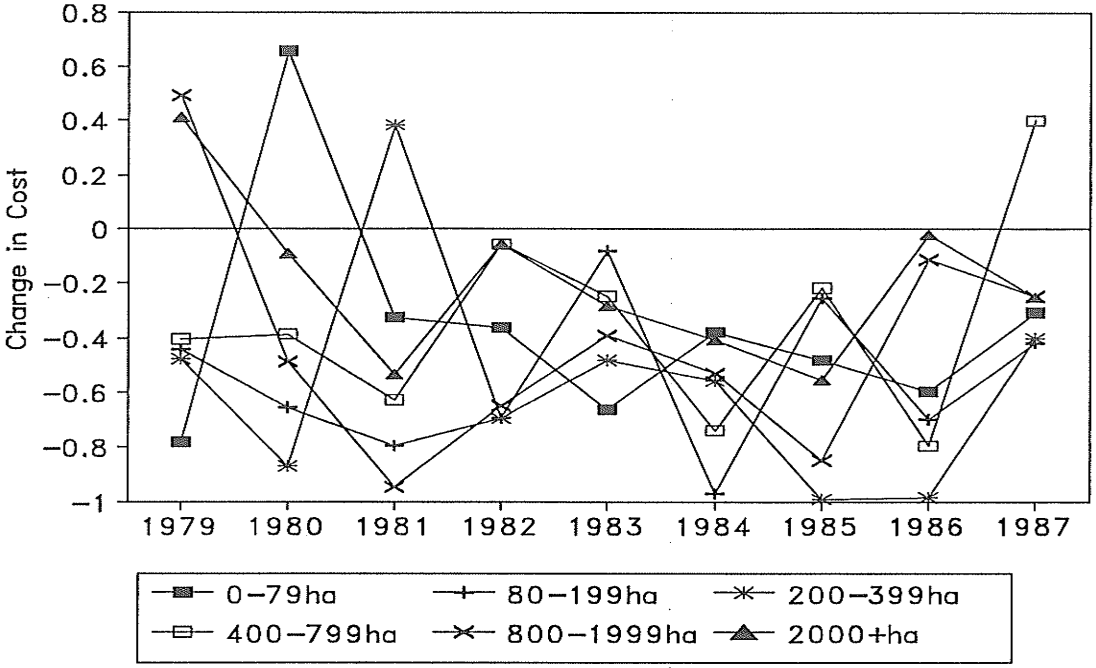

Figure 4.1 Tornqvist Indexes of Changes in Variable Cost.

Productivity for the 400-799 hectares group changed in much the same way as those of smaller producers. Except for 1987 when it fell 40 percent these farmers were able to raise their productivity 34 percent per annum. Farmers operating 800-1999 hectares improved their cost effectiveness (or productivity) by an average of 41 percent per year during the period 1979-87. The largest farmers (operating 2000 hectares or more) appear to have had the poorest relative performance. Table 4.1 suggests that their annual improvement in productivity was only 20 percent. While productivity fell some 40 percent in 1979 this group raised productivity by between 2 and 55 percent each year during this period.

A word about these results is in order. The magnitudes of productivity improvement suggest problems with model specification which may have resulted in overestimation of the changes in factor productivity. An attempt was made to separate the impact of the weather and farmsize (proxied by hectarage operated) on total factor productivity. Three regressions were run in which the tornqvist residual ($1/2[\Gamma_1+\Gamma_o](t_1-t_o)$) from (**2.10**) was the dependent variable. In the first regression rainfall and its quadratic term comprised the explanatory variables to account for the importance of rainfall alone in explaining the calculated productivity changes. In order to control for the effects of rainfall and scale of operation on productivity a second regression was run in which rainfall, average farmsize and their quadratic and interaction terms formed the explanatory variables. In addition to the explanatory variables in the second regression, the third regression incorporated the effect of the interactions of rainfall and average farmsize with relative labour wages, output quantities, and capital stocks. In all three regressions rainfall and land data were transformed by taking natural logarithms since (**2.10**) is in logarithmic form.

Typical of pooled cross-section and time-series data mutual independence of the errors could not be guaranteed in these regressions. For example, grouping the data based on land worked rather than cost of production or output may result in mutual dependence of the error terms. Hence the specification of a fully cross-sectionally correlated and time-wise autoregressive model (Kmenta, 1986:622-625; Fomby, Hill, and Johnson, 1984:325-328). For this purpose the data is arranged such that a complete time-series for the first group is followed by a complete time-series for the second group, and so on. The model can be represented by the system of equations:

$$\begin{array}{c} y_{1t}=\beta_1 x_{11,t}+\beta_2 x_{21,t}+\ldots+\beta_k x_{kI,t}+u_{1t} \\ y_{2t}=\beta_1 x_{12,t}+\beta_2 x_{22,t}+\ldots+\beta_k x_{k2,t}+u_{2t} \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ y_{it}=\beta_1 x_{1i,t}+\beta_2 x_{2i,t}+\ldots+\beta_k x_{ki,t}+u_{it} \end{array} \tag{4.1}$$

$$i=1,2,\ldots,6; \quad t=1,2,\ldots,9; \quad k=1,\ldots,K.$$

where y_{it} is the calculated tornqvist measure of productivity change for the i-th group in the t-th period and k=land, rainfall, and their relevant interactions. Using matrix notation we can more compactly represent this system of equations as

$$Y=X\cdot\mathbf{B}+U \tag{4.2}$$

The underlying assumption of this formulation is that all farm sizes respond in an identical manner to a change in an independent variable so that all structural variation is contained in the error term.

The estimated coefficients (β_is) are shown in Table 4.2 below.The estimates of regression I indicate that rainfall by itself is not a significant factor in explaining the variation of the calculated tornqvist indexes of change in cost of production ($\frac{1}{2}[\frac{\partial \ln C_1}{\partial t}+\frac{\partial \ln C_o}{\partial t}]$). That is β_r and β_{rr} are not significantly different than zero either separately or jointly. Similar results were obtained from regressions II and III. The impacts of both rainfall and land were insignificant.

The residual between the observed and predicted changes in productivity in these regressions can be interpreted as the change that is not accounted for by the changes in input prices, output quantities, capital stocks, land operated and rainfall received. That

Table 4.2 Regression Analysis of the Variation in the Tornqvist Indexes of Cost Changes.

Variable	Regression		
	I	II	III
	Estimate (Std. Error)	Estimate (Std. Error)	Estimate (Std. Error)
Rainfall (β_r)	0.28 (0.31)	-0.28 (1.12)	-0.05 (1.34)
Land (β_h)		0.78 (1.24)	0.43 (1.40)
Land x Rainfall (β_{hr})		-0.15 (0.19)	-0.03 (0.21)
Land x Wages (β_{wh})			-0.06 (0.04)
Land x Output (β_{yh})			0.07 (0.06)
Land x Capital (β_{kh})			-0.08* (0.04)
Rainfall x Wages (β_{wr})			0.06 (0.04)
Rainfall x Output (β_{yr})			-0.09* (0.05)
Rainfall x Capital (β_{kr})			0.07* (0.04)
Land x Land (β_{hh})		0.02 (0.01)	0.04 (0.03)
Rainfall x Rainfall (β_{rr})	-0.05 (0.05)	0.04 (0.17)	-0.05 (0.19)
R^2	0.03	0.35	0.51
Durbin-Watson	1.89	2.02	2.17

Shaded estimates are significant at 95%

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is, change in total factor productivity or equivalently, technical change. Such indexes of

Table 4.3 Residual Changes in Variable Costs: Regression I.

ha (Ave)	0-79 (32.56)	80-199 (120.74)	200-399 (275.97)	400-799 (577.80)	800-1999 (1284.00)	2000+ (6099.15)
1979	-0.32	0.01	-0.02	0.05	0.95	0.87
1980	1.08	-0.23	-0.44	0.04	-0.06	0.34
1981	0.15	-0.32	0.86	-0.15	-0.47	-0.06
1982	0.02	-0.31	-0.31	0.33	-0.27	0.33
1983	-0.29	0.29	-0.11	0.12	-0.02	0.08
1984	0.04	-0.55	-0.13	-0.31	-0.10	0.02
1985	-0.02	0.21	-0.53	0.24	-0.39	-0.09
1986	-0.14	-0.24	-0.53	-0.34	0.34	0.43
1987	0.07	-0.04	-0.02	0.78	0.13	0.13
Ave.	0.06	-0.13	-0.14	0.08	0.01	0.23

productivity change are presented in Tables 4.3, 4.4, and 4.5 for regressions I, II and III respectively. Note that these calculations are not necessarily more reliable than the Tornqvist results in Table 4.1, since rainfall and farm size were insignificant in the regressions in Table 4.2.

According to results of regression I (Table 4.3), farmers working less than 400 hectares fared better than their larger counterparts. Farmers whose average land was 32 hectares experienced productivity loss of 6 percent while those between 200 and 399 hectares (average 120 ha) improved their cost effectiveness by 13 percent per year. Cost efficiency of producers operating on average 275 hectares rose nearly 14 percent annually. On the other hand productivity declined by 8.5, 1.3 and 23 percent for the three largest groups (more than 400 hectares), respectively. Results of regression II (see Table 4.4) show that those farmers below 80 hectares had a productivity loss of 14 percent per year

Table 4.4 Residual Change in Variable Cost: Regression II.

ha (Mean)	0-79 (32.56)	80-199 (120.74)	200-399 (275.97)	400-799 (577.80)	800-1999 (1284.00)	2000+ (6099.15)
1979	-0.26	0.10	0.06	0.10	0.94	0.69
1980	1.15	-0.14	-0.38	0.06	-0.10	0.09
1981	0.20	-0.22	0.95	-0.09	-0.46	-0.18
1982	0.11	-0.23	-0.27	0.32	-0.34	0.06
1983	-0.20	0.37	-0.08	0.10	-0.13	-0.25
1984	0.12	-0.46	-0.07	-0.30	-0.15	-0.25
1985	0.04	0.30	-0.45	0.29	-0.39	-0.32
1986	-0.08	-0.15	-0.45	-0.30	0.32	0.23
1987	0.16	0.04	0.02	0.77	0.04	-0.18
Average	0.14	-0.04	-0.07	0.10	-0.03	-0.01

and those working 121 hectares gained 4 percent annually. Producers cultivating 276 hectares improved their cost effectiveness by 7.5 percent per year. Cost effectiveness declined 10.6 percent per year for the group averaging 578 hectares and rose 3.1 and 1.3 percent annually for the largest two groups. Again, the larger producers appear to have had bigger loss in productivity than the smaller ones. Regression III reveals the same results, namely that the larger farmers had bigger loss in productivity than the smaller ones (see Table 4.5). However, as a result of having more explanatory variables the magnitudes of the changes are smaller than in the other two regressions, and appear more reasonable. In this sense it is an improvement over the tornqvist results.

These results reveal the same pattern as those obtained using the tornqvist divisia method in one respect: the medium sized farmers appear to have fared better than the smallest and largest farmers. However, results differ in the magnitudes of productivity

Table 4.5 Residual Change in Variable Costs: Regression III.

ha **(Mean)**	**0-79** **(32.56)**	**80-199** **(120.74)**	**200-399** **(275.97)**	**400-799** **(577.80)**	**800-1999** **(1284.00)**	**2000+** **(6099.15)**
1979	-0.31	0.12	-0.02	0.10	0.89	0.48
1980	0.86	-0.08	-0.42	-0.00	-0.14	-0.03
1981	0.10	-0.19	0.82	-0.12	-0.53	-0.30
1982	-0.08	-0.17	-0.34	0.38	-0.30	0.12
1983	-0.37	0.50	-0.14	0.17	-0.07	-0.32
1984	0.07	-0.33	-0.06	-0.22	-0.14	-0.14
1985	-0.06	0.44	-0.35	0.28	-0.40	-0.27
1986	-0.04	-0.30	-0.44	-0.24	0.31	0.38
1987	0.22	0.17	0.09	0.89	0.10	-0.06
Ave.	0.04	0.02	-0.10	0.14	-0.03	-0.02

improvement and indeed often in the direction of technical change. In contrast to Table 4.1, technical regress, $\frac{1}{2}(\Gamma_1+\Gamma_o)(t_1-t_o)>0$, is often obtained in Tables 4.3-4.5.

4.2 Econometric Estimation

The structure of the technology of production was econometrically estimated using a system of three equations:(i) a single-output short-run cost function, (ii) the labour share equation (from the cost function by application of Shephard's lemma) and (iii) the revenue share equation, assuming profit maximization. The single output is obtained by aggregating the individual outputs using the divisia index method. It was necessary to estimate the cost function in order to obtain an estimate of the direction of bias of technical change and technical input substitutability. The cost shares of the variable inputs sum to one by design. Therefore only the labour share equation was included. The system was specified thus:

$$
\begin{aligned}
\text{[1]}\quad lnC(\omega,Y,K,R,h,t) = {} & \alpha_o+\alpha_2 D_2+\alpha_3 D_3+\alpha_4 D_4+\alpha_5 D_5+\alpha_6 D_6 \\
& +\alpha_{d2t} D_2 t+\alpha_{d3t} D_3 t+\alpha_{d4t} D_4 t+\alpha_{d5t} D_5 t+\alpha_{d6t} D_6 t \\
& +\alpha_\omega \ln\omega+\alpha_y lnY+\alpha_k lnK+\alpha_r \ln R+\alpha_h lnh+\alpha_f \ln f+\alpha_t t \\
& +\alpha_{\omega\omega}(\ln\omega)^2+\alpha_{\omega y}\ln\omega\ln Y+\alpha_{\omega k}\ln\omega\ln K+\alpha_{\omega r}\ln\omega\ln R \\
& +\alpha_{\omega h}\ln\omega\ln h+\alpha_{\omega t} t\ln\omega+\alpha_{yy}(lnY)^2+\alpha_{yk} lnY\, lnK+\alpha_{ry} lnY\, lnR \\
& +\alpha_{yh} lnY\, lnh+\alpha_{yt} t\, lnY+\alpha_{kk}(lnK)^2+\alpha_{kr} lnK\, lnR+\alpha_{kh} lnK\, lnh \\
& +\alpha_{kt} t\, lnK+\alpha_{rr}(\ln R)^2+\alpha_{rh}\ln R\ln h+\alpha_{rt} t\ln R \\
& +\alpha_{hh}(\ln h)^2+\alpha_{ht} t\ln h+\alpha_{tt} t^2
\end{aligned}
\tag{4.3}
$$

$$
\begin{aligned}
\text{[2]}\quad \frac{\partial\ln C(.)}{\partial\ln\omega} \equiv \frac{\omega\cdot X_L}{C} = {} & \gamma_o+\gamma_\omega\ln\omega+\gamma_y lnY+\gamma_k lnK+\gamma_r lnR \\
& +\gamma_h\ln h+\gamma_f\ln f+\gamma_t t
\end{aligned}
$$

$$
\begin{aligned}
\text{[3]}\quad \frac{\partial lnC(.)}{\partial lnY} = \frac{p\cdot Y}{C} = {} & \delta_o+\delta_\omega\ln\omega+\delta_y\ln Y+\delta_k lnK+\delta_r lnR+\delta_h lnh \\
& +\delta_f\ln f+\delta_t t
\end{aligned}
$$

where $\omega=\frac{\omega_L}{\omega_F}$, L=labour and F=fertilizers; X_L is the number of farm workers and family members employed in the production; Y is the single aggregate output; p is the divisia output price index; K=capital stocks; R=rainfall for the months of December, January and February; h=hectarage of land operated;f is the number of farmers in each category to capture the behaviour of marginal farmers; t=0,1,...,9, the time trend proxying technical change; and $D_2,\ldots,D_6$ are dummies for the largest five farmsizes to enable comparison across groups. Cost is defined as total variable cost per farm normalized on the price of fertilizer. This way we also imposed the condition of linear homogeneity of cost in factor prices.

4.2.1 Tests of Hypotheses

The three equation system was unrestricted and was estimated using an iterated seemingly unrelated regressions procedure. The unrestricted model provided an opportunity to test for two important hypotheses concerning the behaviour of the producers, namely, cost minimization and profit maximization. Table 4.6 gives the parameter estimates.

Cost minimization was tested via the cross-equation coefficient restrictions implied by Shephard's lemma:

$$\begin{gathered} H_o\!: \alpha_{\omega}=\gamma_o; \quad \alpha_{\omega\omega}=\gamma_{\omega}; \quad \alpha_{\omega Y}=\gamma_Y \\ \alpha_{\omega k}=\gamma_k; \quad \alpha_{\omega r}=\gamma_r; \quad \alpha_{\omega h}=\gamma_h; \\ \alpha_{\omega f}=\gamma_f; \quad \alpha_{\omega t}=\gamma_t. \end{gathered}$$

The underlying argument is that if cost minimization holds then we can apply Shephard's lemma so that the labour share equation can be derived from the cost function. Cost minimization was strongly rejected at 95 percent confidence level using Wald's chi-square.

Table 4.6 Estimates of the Unrestricted Three-Equation System (Standard Errors in Parentheses).

α_o	325.80* (61.47)	α_y	-2.04 (2.40)	α_{yk}	0.60* (0.15)	α_{ht}	0.18* (0.07)	γ_f	0.00 (0.03)
α_2	-1.54* (0.44)	α_h	6.62* (2.35)	α_{yh}	-0.56* (0.19)	α_{rr}	6.98* (1.14)	γ_t	0.01 (0.01)
α_3	-2.19* (0.70)	α_r	-99.07* (16.51)	α_{yr}	-0.30 (0.38)	α_{rf}	0.40 (0.24)	δ_o	-7.15 (7.71)
α_4	-5.31* (0.92)	α_f	2.83 (2.45)	α_{yf}	0.01 (0.13)	α_{rt}	0.38* (0.07)	δ_w	-0.51* (0.20)
α_5	-6.56* (1.16)	α_t	0.78 (0.55)	α_{yt}	0.01 (0.04)	α_{ff}	-0.12 (0.78)	δ_k	-0.10 (0.24)
α_6	-8.01* (1.57)	α_{ww}	0.05 (0.06)	α_{kk}	-0.11 (0.11)	α_{ft}	-0.09* (0.04)	δ_y	-0.01 (0.32)
α_{d2t}	0.11 (0.08)	α_{wy}	-0.13 (0.12)	α_{kh}	-0.26 (0.15)	α_{tt}	0.01* (0.00)	δ_h	0.23 (0.25)
α_{d3t}	0.19 (0.14)	α_{wk}	0.09 (0.06)	α_{kr}	-0.61* (0.26)	γ_o	-0.49 (0.97)	δ_r	2.36* (0.92)
α_{d4t}	0.60* (0.18)	α_{wh}	0.01 (0.07)	α_{kf}	-0.50* (0.13)	γ_w	0.15* (0.03)	δ_f	1.24* (0.19)
α_{d5t}	0.85* (0.23)	α_{wr}	1.57* (0.39)	α_{kt}	-0.14* (0.03)	γ_k	-0.03 (0.04)	δ_t	0.15* (0.05)
α_{d6t}	1.11* (0.32)	α_{wf}	0.29* (0.07)	α_{hh}	0.14 (0.08)	γ_y	0.00 (0.05)		
α_w	-11.96* (3.06)	α_{wt}	-0.00 (0.02)	α_{hr}	0.34 (0.31)	γ_h	-0.01 (0.04)		
α_k	5.09* (2.16)	α_{yy}	-0.11 (0.11)	α_{hf}	0.07 (0.13)	γ_r	0.05 (0.15)		

R^2=0.9991; Shaded coefficient estimates are significant at 95%.

Similarly, the logic behind the restrictions necessary for testing for profit maximization runs along the following line: if marginal pricing of output holds, then the revenue share equation can be derived from the cost function by simply taking the first derivative. Consequently the following additional coefficient restrictions for the profit maximization test were imposed:

$$\begin{gathered} H_o\text{:}\ \alpha_y=\delta_o;\quad \alpha_{yy}=\delta_y;\quad \alpha_{\omega y}=\delta_{\omega} \\ \alpha_{yk}=\delta_k;\quad \alpha_{yr}=\delta_r;\quad \alpha_{yh}=\delta_h \\ \alpha_{yf}=\delta_f;\quad \alpha_{yt}=\delta_t. \end{gathered}$$

Since profit maximization is a more restrictive assumption than cost minimization, rejection of cost minimization would be strong indication that profit maximization would be rejected. It was, therefore, not surprising that the null hypothesis of profit maximization was also rejected at 95 percent level by Wald's chi-square, suggesting that producers were not maximizing profits.

The hypothesis of constant returns to scale was also tested. Intuitively, constant returns to scale in production for the cost function implies that doubling output and the quasi-fixed inputs doubles the variable costs. That is,

$$C(\omega,\lambda Y,\lambda K,R,\lambda h,t)=\lambda C(\omega,Y,K,R,h,t)$$

where λ is any positive scalar. A test for constant returns to scale was therefore designed as a test of linear homogeneity of variable cost in production. For our translog cost function this test is equivalent to the following restrictions :

$$H_o: \quad \alpha_y+\alpha_k+\alpha_h=1$$
$$\alpha_{yy}+\alpha_{kk}+\alpha_{hh}+\alpha_{yk}+\alpha_{yh}+\alpha_{kh}=0$$

The null hypothesis (H_o) that variable cost is linear homogeneous in output, capital and land was rejected. This means that doubling output, land and capital jointly does not double the variable costs. In turn this means that production technology does not exhibit constant returns to scale. In addition homotheticity was rejected at ninety five percent using Wald's chi-square test. This implies that the ratio of inputs (or cost shares) is not independent of the scale of production.

The last hypothesis tested involved disembodied technical change. Defining disembodied technical change as a reduction in cost that is independent of any input prices, output, capital, land, rainfall and number of producers, its test implied the restriction $\alpha_{wt}=\alpha_{yt}=\alpha_{kt}=\alpha_{ht}=\alpha_{ft}=\alpha_{rt}=0$. The null hypothesis that technical change was disembodied (i.e. H_o: $\alpha_{wt}=\alpha_{yt}=\alpha_{kt}=\alpha_{ht}=\alpha_{ft}=\alpha_{rt}=0$) was rejected at the ninety five percent level using Wald's Chi-square test. This implies evidence of embodied technical change. Table 4.7 presents a summary of the hypotheses tests.

4.2.2 Interpretation of Econometric Results

All the intercepts of the cost function (α_o, α_2,...,α_6) were significant. The labour share increases with relative labour wages (γ_w>0) while the share of revenues fell with relative wages (δ_w<0), and rose with rainfall, number of producers and with technical progress (δ_r, δ_f, δ_t>0).

The estimates α_{wt}, α_{yt}, α_{kt}, α_{rt}, α_{ht}, and α_{ft} indicate the bias of technical change

Table 4.7 Summary of Hypotheses Tests (at 95% level).

Test	No. of Restrictions	Wald's X^2	Critical X^2	Probability of Error II	Decision
Cost Minimization	7	65.45	14.07	0.00	Reject H_o
Profit Maximization	7	44.63	14.07	0.00	Reject H_o
CRTS	2	21.97	5.99	0.00	Reject H_o
Homotheticity	6	51.31	12.59	0.00	Reject H_o
Disembodied Technology	6	68.58	12.59	0.00	Reject H_o

toward labour, scale of operation, capital, amount of rainfall received, average size of land, and number of producers, respectively. Results indicate that technical change was neutral with respect to wages and output, capital using and land-saving. These results also suggest that technical change negatively impacted on the marginal farmers. A positive and significant α_{rt} suggests that the impact of additional rainfall on average cost increased over time. This implies that rainfall had a smaller effect in reducing cost of production as better techniques were adopted.

Marginal costs $(\partial C/\partial y)$ were found to remain constant as output increased ($\alpha_{yy}=0$). This was also true for rainfall, number of farmers, and relative farm wages. That is there was no change in marginal cost as output, rainfall, relative farm wages and number of producers separately increased. However, marginal cost fell as land increased and rose with an increase in capital stocks.

Table 4.8 Percentage Changes in Variable Costs due to Technical Change (∂lnC/∂t).

average farmsize	**32.56**	**120.74**	**275.97**	**577.80**	**1284.00**	**6099.15**
1978	0.06	-0.09	-0.12	-0.12	-0.05	-0.07
1979	0.04	-0.11	-0.17	-0.15	-0.08	-0.13
1980	0.06	-0.12	-0.18	-0.16	-0.09	-0.18
1981	0.15	-0.04	-0.18	-0.08	0.00	-0.05
1982	0.02	-0.12	-0.24	-0.16	-0.09	-0.14
1983	-0.02	-0.10	-0.26	-0.15	-0.10	-0.17
1984	0.07	-0.05	-0.17	-0.07	-0.03	-0.28
1985	0.08	0.00	-0.11	0.01	0.01	-0.24
1986	0.05	-0.21	-0.20	0.08	0.06	-0.21
1987	-0.01	-0.14	-0.31	0.01	0.00	-0.24
Annual change	0.05	-0.10	-0.19	-0.08	-0.04	-0.17

The (negative) shadow price of capital decreased in magnitude with number of producers and with increasing rainfall but remains virtually unchanged as land and capital rise. The (negative) shadow price of land ($\partial C/\partial h$) also remains constant with an expansion of land operated (α_{hh}=0). This is consistent with diminishing marginal productivity of land. Another interesting result concerned the impact of rainfall on variable cost. At the margin, the impacts of rainfall on the change in variable costs due to rainfall was positive and significant (α_{rr}>0). This suggests that more rainfall results in further cost reduction.

Following the structural estimation of **(4.3)** above the derivative of the estimated

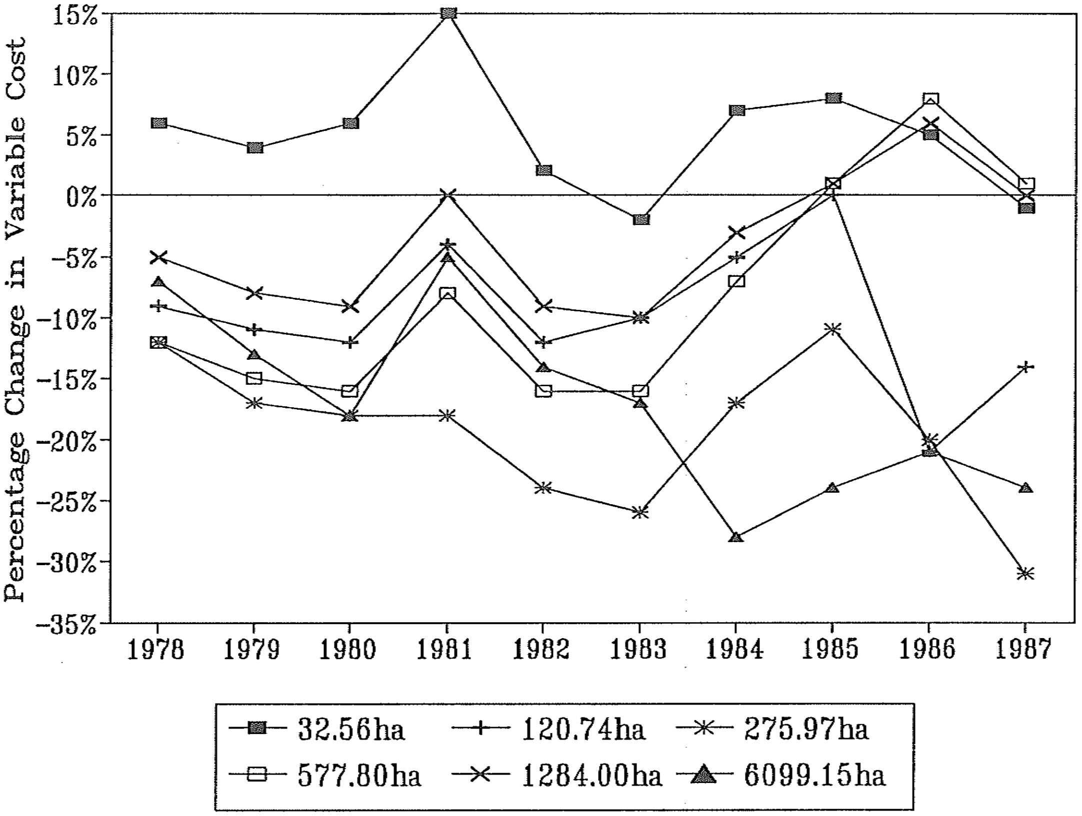

Figure 4.2 Percentage Change in Variable Costs ($\partial \ln C/\partial t$).

cost function with respect to time was evaluated for each data point. Assuming that technical change is captured by the trend variable, this derivative (evaluated at observed (ω, Y, K, R, h)) therefore gives the impact of technological change on variable costs. The results are presented in Table 4.8 while Figure 4.2 is a graphical representation. These results suggest that technical progress generally declined over the period for all the farmers and became negative (technical regress) in the more recent years for some farmers. This is illustrated quite clearly in Figure 4.2 in which an upward trend in percentage change in cost is discernable. A positive percentage change in cost implies that cost increased with technical. In turn this means productivity fell with changing techniques.

Table 4.8 also shows that farmers with an average of 120 hectares had a 10 percent annual increase in productivity during the period under study. Those farmers working 276 and 578 hectares had a productivity gains of 19 and 8 percent per year, respectively while the largest two farm sizes (1284 and 6099 hectares) improved their productivity annually by 4 and 17 percent. These results further suggest that the smallest farmers had the worst performance. In fact they appear to have had average productivity losses of 5 percent per year.

How do these results compare across farm sizes? That is, what is the relative productivities of the different sizes? This question is answered in Table 4.9. Figure 4.3 presents the same results. According to Table 4.9 farmers with 120 hectares on average were 13 percent more productive than those working 32 hectares. The 276, 578, 1284, and 6099 hectares groups were respectively 42, 179, 193, and 221 percent more productive than the 32 hectare farmers. However, over time all of these groups were becoming less productive than their comparison. Figure 4.3 suggests that by 1985 the 32 hectare group was most productive.

We now turn to a brief discussion of elasticities. By definition, an elasticity is the percentage increase/decrease in one variable as a response to a one percent increase in another. Therefore, elasticities are important for policy designing and evaluation. For a translog cost function these elasticities are equal to the first derivatives:

Table 4.9 Productivities of the Largest Five Farm Sizes Relative to the Smallest Group (32 hectares) i.e $\partial \ln C/\partial D_i$ (i=2,...,6)

average farmsize	D2	D3	D4	D5	D6
1978	-1.65	-2.33	-5.50	-6.81	-8.28
1979	-1.53	-2.13	-4.90	-5.95	-7.15
1980	-1.42	-1.93	-4.30	-5.09	-6.02
1981	-1.31	-1.73	-3.69	-4.22	-4.90
1982	-1.19	-1.53	-3.09	-3.36	-3.77
1983	-1.08	-1.32	-2.48	-2.50	-2.64
1984	-0.96	-1.12	-1.88	-1.64	-1.52
1985	-0.85	-0.92	-1.28	-0.78	-0.39
1986	-0.73	-0.72	-0.67	0.09	0.74
1987	-0.62	-0.51	-0.07	0.95	1.86
mean	-1.13	-1.42	-2.79	-2.93	-3.21

$$\frac{\partial \ln C}{\partial \ln z} = \frac{z}{C} \cdot \frac{\partial C}{\partial z} = \varepsilon_z$$

where $z=(\omega, Y, K, R, h)$. A positive elasticity implies that variable costs increase with a one percentage increase in z. The calculated elasticities are presented in Appendix II.

The elasticities of cost with respect to relative farm wages were positive for all the observations. Positive elasticities imply that variable costs increase with an increase in relative labour wages. It is worthwhile to note that these elasticities were greater than one for farmers operating 33 hectares. This suggests that a one percent increase in relative

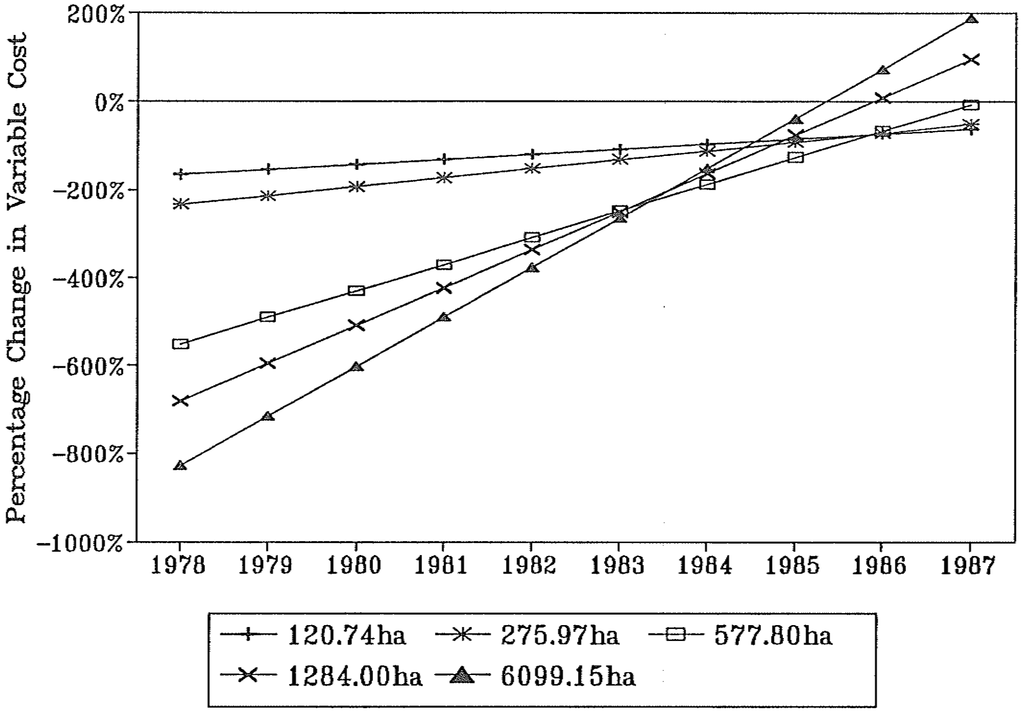

Figure 4.3 Productivities of Largest Five Farm Sizes Relative to the Smallest.

wages resulted in a greater than proportionate increase in variable costs for these farmers. This is perhaps due to the large component of family labour which may be insensitive to changes in wages.

Output elasticities were all positive, implying that variable cost increases with increasing output. Equivalently, marginal cost increases with an increase in output. These elasticities were greater than one at three out of every four observations so that variable costs increase more than proportionately in response to a one percent increase in the aggregate output.

A positive cost elasticity with respect to capital stocks implies that variable costs increase with stocks of capital. Alternatively, a negative elasticity implies that variable costs decrease with increasing capital stocks. In theory the potential of more capital stocks to reduce variable costs is given by a negative elasticity. In this study capital elasticities of variable cost were negative for only five percent of the observations. This means that a one percent increase in capital stocks would generally increase variable costs. This result is surprising since it suggests a negative marginal product of capital.

The rainfall elasticity is negative more than sixty percent of the time and evenly distributed between small and larger farmers. About half of the observations had elasticities less than minus one implying that a one percent increase in rainfall results in a more than one percent decrease in variable costs. Results also show that land elasticity was negative forty percent of the time and predominantly negative in the more recent years.

4.3 Comments

This study assumed that the underlying cost function was translog for all producers. Two considerations were in the forefront when selecting the functional form, namely (i) the desire for exact aggregation for the tornqvist indexing approach, and (ii) flexibility requirements for the econometric estimations.

Results of the tornqvist index calculations implied that costs declined for all farmers, that is there was technical progress. In addition, these results suggest that smaller producers were more cost effective than the larger ones. However, it is important to note that these results do not account for the impact of land and rainfall in a direct manner, so that the calculated magnitude of technical progress is unusually large. To correct for omitted variables regressions were run in which the tornqvist residual was endogenous and rainfall and land and their interaction with each other and with output levels, relative labour wages, and capital stocks constituted the exogenous variables. However, these additional variables were generally insignificant in these regressions. After correction for these regression results, the index number calculations (i.e. residual between observed and predicted values) again indicate that smaller farmers were more cost effective than the larger ones. In contrast to the initial calculations, technical progress is much smaller in magnitude and is often negative, implying technical regress.

An important inconsistency in this methodology requires highlighting. Recall that returns to capital were calculated under the assumption of constant returns to scale. Under this assumption returns to capital were obtained as a residual after payments to all variable inputs. However, these residual returns include returns to other quasi-fixed inputs, particularly land. This results in an upward bias of the shadow price of capital. As a result regressing the tornqvist residual $\frac{1}{2}[\Gamma_1+\Gamma_o](t_1-t_o)$ against land and rainfall is inherently inconsistent because the impact of capital indirectly includes the contribution of land through the calculation of the shadow price of capital (see equation (**3.3**)). A more consistent way to incorporate land and rainfall directly into the Tornqvist formula is to use shadow prices from, for example, econometric estimations. However, this two step approach provides no additional insight to econometrics. In other words, there is no obvious gain in performing the tornqvist calculations after doing econometric estimations.

Which of the two methods gives more reliable results? Unlike the tornqvist indexing method, no prior restrictions on producer behaviour and the structure of the production technology are imposed in the econometric approach. Rather, constant returns to scale, cost minimization, profit maximization, and disembodied technical change were all tested for and rejected. In addition, econometrics allowed for systematic and consistent incorporation of land and rainfall directly into the analysis rather than by employing a two step procedure which may involve inconsistencies.

In sum, econometric results seem more believable than the index number calculations, and land and rainfall are incorporated more appropriately into the econometric analysis. Therefore the econometric calculations of technical change (see Table 4.8) are more reliable.

Chapter 5

Summary and Conclusions

In Chapter 4 we presented the empirical results. Here we summarize the major findings and give some concluding remarks. Lastly, we also give some caveats about the scope of the study and suggestions for future research.

5.1 Summary

This study set out to measure productivity changes for six groups of commercial farmers and, as a natural extension, to determine the sources of these changes. Assuming a common functional form for the technologies (embodied by translog cost function) for all producers two techniques for measuring multifactor productivity (or technical change) were implemented. Results from the tornqvist index calculations imply that smaller producers had larger productivity gains than the larger ones. Cost of production declined 49 percent and 32 percent for producers under 400 and over 400 hectares, respectively. The magnitudes of the changes suggested methodological flaws so that upon incorporating the rainfall and land factors these numbers fall to 7 percent decrease for the smaller farmers and a rise of 10 percent for the larger producers.

A more systematic approach to measuring the changes in variable costs as time proceeds was undertaken through econometrics. An unrestricted three-equation model was estimated using an iterated Zellner's technique. The hypotheses of cost minimization, profit maximization, constant returns to scale, homotheticity, and disembodied technological change were all strongly rejected. The shadow price of capital fell with increasing amounts of rainfall and number of producers and improvements in techniques of production. The pseudo rental rate of land rose with technical improvement.

Farmers operating more than 80 hectares had productivity gains of between four and nineteen percent annually whereas those below 80 hectares had losses of five percent annually. Two groups (working 276 and 6099 hectares) appear to have gained in productivity over the period. The rest were becoming less efficient so that in the later years all suffered productivity losses (Table 4.8 and Figure 4.2).

Technical change was found to be neutral with respect to scale and wages, but capital-saving and land-using. The impact of technical progress on variable costs decreased in magnitude with rainfall. Elasticities showed that costs increased in response to a one percent increase in relative wages, output, and capital, and decreased more than proportionate in reaction to a percentage increase in rainfall. The effect of land was mixed: cost increased for the smaller farmers and generally decreased for the larger farmers in response to a one percent increase in land operated.

The effects of $D_2,...,D_6$ on cost gave the productivities of the largest five groups of farmers relative to the smallest farmers. It was found that initially all the larger farmers were more productive than those operating an average of 32 hectares. However, these larger farmers were quickly becoming less productive (relative to the 32 hectare group) so that by 1985 the smaller farmers had become the most productive.

5.2 Conclusions

Some conclusions can be drawn from the findings of this study, the obvious one being that farmers were neither minimizing costs nor maximizing profits. This may be attributed to the policies whose stated primary objective was income [re]distribution so that producers did not respond to the policy environment by employing cost-reducing techniques.

We can also conclude that the general policy of favouring smaller producers was not achieved. Evidence suggests that small farmers (less than 80 hectares) suffered rising costs while the larger farmers (more than 80 hectares) had moderate productivity gains. Evidence also suggests that relative to farmers working an average of 32 hectares, large farmers became less productive over time leading to the conclusion that the policy environment obtaining was affecting larger farmers more adversely.

5.3 Caveats and Suggestions for Further Research

Interpretation of the results must be done against the backdrop of the answer to one fundamental question, namely: Are the results plausible? To address this question a brief review of the assumptions invoked is apt. One, the model was constrained apriori to meet the requirement of linear homogeneity in factor prices which implies that only relative prices matter. However, violation of this condition will affect the quality of the results. This may have been the case in this study. Two, production technology was characterized by translog cost functions for all producers. This provides a second order approximation to an arbitrary set of technologies. However, this may not necessarily provide a close approximation to the true set of technologies. Relaxing this particular assumption could yield useful insights. Three, the technology is assumed to be known by farmers with certainty. That is, the effects of weather on yields are predicted without error at the time of input decisions. However, yields are not known with certainty and farmers are presumably risk averse. In this case the cost function model employed here is misspecified. Four, technical change was assumed exogenous and closely associated with the time trend (or disembodied). Endogenizing technical change and specifying a more general index for it could conceivably yield interesting results. Five, the marginal productivity value of hired labour was allowed to be the same as that of family labour. In addition labour, including that which is supplied by family members, was treated as variable. These constitute misspecification and allow no inference about the relative roles of the two labour types. Six, grouping farmers according to the amount of land operated may be inappropriate: land operated was not adequately defined. For example, it is not exactly clear how the communal grazing lands are treated; some of the smaller farmers raise their cattle solely on communal grazing lands.

Perhaps the most important shortcoming of this study is the inability to separate the impact of factors that are important in improving total factor productivity, namely, expenditures on research and development and extension services, and investment in education. This implies that investment streams and therefore capital stocks are underestimated.

APPENDICES

Appendix I: Cost Shares

Input Shares

year	Average farm size (ha)	labor	fertilizer	capital
1978	34.14	0.83	0.17	1.08
1979	33.02	0.89	0.11	0.63
1980	28.14	0.89	0.11	0.40
1981	26.39	0.82	0.18	0.82
1982	30.99	0.85	0.15	0.46
1983	36.12	0.91	0.09	0.83
1984	34.71	0.94	0.06	0.77
1985	33.49	0.93	0.07	0.60
1986	32.90	0.55	0.45	5.84
1987	35.73	0.61	0.39	4.35
1978	123.24	0.70	0.30	1.86
1979	120.69	0.61	0.39	0.76
1980	122.16	0.82	0.18	0.29
1981	121.37	0.81	0.19	0.95
1982	119.50	0.80	0.20	0.47
1983	113.39	0.77	0.23	0.70
1984	115.58	0.80	0.20	0.61

year	Average farm size (ha)	labor	fertilizer	capital
1985	119.32	0.93	0.07	0.67
1986	125.04	0.89	0.11	0.24
1987	127.15	0.79	0.21	1.86
1978	276.41	0.85	0.15	0.11
1979	276.67	0.52	0.48	0.11
1980	278.14	0.73	0.27	0.28
1981	277.59	0.77	0.23	-0.25
1982	269.37	0.77	0.23	0.28
1983	286.53	0.79	0.21	0.62
1984	284.37	0.63	0.37	0.51
1985	283.38	0.71	0.29	0.94
1986	267.05	0.84	0.16	1.30
1987	260.19	0.79	0.21	0.29
1978	557.36	0.73	0.27	0.34
1979	557.56	0.66	0.34	0.28
1980	576.82	0.74	0.26	0.55
1981	573.27	0.67	0.33	0.44
1982	567.78	0.66	0.34	0.21
1983	595.64	0.54	0.46	0.16
1984	606.04	0.67	0.33	0.10

year	Average farm size (ha)	labor	fertilizer	capital
1985	577.61	0.78	0.22	0.32
1986	577.08	0.68	0.32	0.48
1987	588.83	0.37	0.63	-0.26
1978	1392.40	0.57	0.43	1.43
1979	1243.03	0.74	0.26	0.26
1980	1266.34	0.82	0.18	0.81
1981	1242.56	0.50	0.50	1.34
1982	1194.29	0.69	0.31	1.54
1983	1310.10	0.65	0.35	0.87
1984	1306.58	0.67	0.33	1.36
1985	1248.66	0.62	0.38	2.13
1986	1345.50	0.73	0.27	1.71
1987	1290.49	0.56	0.44	1.42
1978	4872.85	0.88	0.12	0.68
1979	5466.12	0.68	0.32	-0.02
1980	6719.61	0.88	0.12	-0.12
1981	4630.68	0.84	0.16	0.43
1982	4960.56	0.85	0.15	0.37
1983	6184.40	0.88	0.12	0.38
1984	7352.12	0.89	0.11	0.30

year	Average farm size (ha)	labor	fertilizer	capital
1985	8117.09	0.90	0.10	0.60
1986	6390.30	0.92	0.08	0.39
1987	6297.81	0.72	0.28	0.47

Livestock and Livestock Products Shares

year	Average farm size (ha)	cattle	milk	eggs	poultry	pigs
1978	34.14	0.12	0.01	0.30	0.48	0.39
1979	33.02	0.07	0.01	0.08	0.22	0.39
1980	28.14	0.11	0.04	0.21	0.20	0.27
1981	26.39	0.15	0.01	0.54	0.21	0.06
1982	30.99	0.14	0.01	0.21	0.18	0.45
1983	36.12	0.09	0.05	0.22	0.22	0.62
1984	34.71	0.11	0.00	0.09	0.58	0.40
1985	33.49	0.17	0.05	0.07	0.42	0.34
1986	32.90	0.96	0.08	0.48	1.51	0.50
1987	35.73	0.77	0.04	0.15	1.21	0.51
1978	123.24	0.25	0.22	1.24	0.02	0.01
1979	120.69	0.40	0.10	0.25	0.01	0.02
1980	122.16	0.09	0.12	0.03	0.35	0.02
1981	121.37	0.21	0.17	0.04	0.25	0.04
1982	119.50	0.05	0.23	0.11	0.13	0.17
1983	113.39	0.12	0.00	0.34	0.11	0.01

year	Average farm size (ha)	cattle	milk	eggs	poultry	pigs
1984	115.58	0.05	0.01	0.05	0.14	0.04
1985	119.32	0.11	0.09	0.60	0.19	0.01
1986	125.04	0.08	0.01	0.12	0.07	0.04
1987	127.15	0.39	0.01	0.22	0.17	0.14
1978	276.41	0.38	0.00	0.02	0.01	0.07
1979	276.67	0.37	0.01	0.01	0.03	0.02
1980	278.14	0.05	0.03	0.02	0.42	0.01
1981	277.59	0.06	0.01	0.01	0.29	0.00
1982	269.37	0.15	0.20	0.00	0.07	0.09
1983	286.53	0.79	0.02	0.00	0.02	0.01
1984	284.37	0.04	0.01	0.00	0.02	0.05
1985	283.38	0.17	0.02	0.02	0.23	0.08
1986	267.05	0.52	0.01	0.43	0.40	0.03
1987	260.19	0.34	0.02	0.11	0.15	0.05
1978	557.36	0.32	0.12	0.03	0.04	0.01
1979	557.56	0.22	0.11	0.05	0.30	0.00
1980	576.82	0.06	0.16	0.01	0.06	0.06
1981	573.27	0.05	0.11	0.01	0.34	0.01
1982	567.78	0.09	0.02	0.03	0.50	0.01

year	Average farm size (ha)	cattle	milk	eggs	poultry	pigs
1983	595.64	0.02	0.21	0.07	0.44	0.14
1984	606.04	0.17	0.14	0.00	0.16	0.13
1985	577.61	0.33	0.28	0.07	0.13	0.04
1986	577.08	0.09	0.04	0.01	0.00	0.02
1987	588.83	0.06	0.04	0.02	0.13	0.02
1978	1392.40	0.44	0.05	0.08	0.16	0.07
1979	1243.03	0.15	0.04	0.07	0.04	0.07
1980	1266.34	0.26	0.09	0.12	0.37	0.07
1981	1242.56	0.27	0.10	0.15	0.42	0.08
1982	1194.29	0.32	0.17	0.07	0.63	0.10
1983	1310.10	0.20	0.12	0.02	0.23	0.04
1984	1306.58	0.29	0.03	0.11	0.06	0.10
1985	1248.66	0.83	0.22	0.13	0.46	0.14
1986	1345.50	0.52	0.03	0.04	0.36	0.01
1987	1290.49	0.69	0.03	0.02	0.13	0.02
1978	4872.85	0.46	0.09	0.03	0.61	0.04
1979	5466.12	0.37	0.03	0.00	0.11	0.01
1980	6719.61	0.34	0.00	0.01	0.05	0.06
1981	4630.68	0.45	0.05	0.03	0.05	0.10

year	Average farm size (ha)	cattle	milk	eggs	poultry	pigs
1982	4960.56	0.62	0.07	0.00	0.05	0.04
1983	6184.40	0.35	0.03	0.03	0.13	0.03
1984	7352.12	0.28	0.03	0.05	0.09	0.03
1985	8117.09	0.36	0.01	0.05	0.31	0.09
1986	6390.30	0.33	0.02	0.02	0.16	0.11
1987	6297.81	0.31	0.01	0.06	0.13	0.11

Crops Shares

year	Average farm size (ha)	maize	s/maize	tobacco	wheat	soybeans	s/cotton	s/flowers	potatos
1978	34.14	0.62	0.00	0.12	0.00	0.00	0.02	0.01	0.01
1979	33.02	0.71	0.01	0.10	0.00	0.00	0.02	0.01	0.01
1980	28.14	0.39	0.00	0.08	0.00	0.00	0.04	0.05	0.00
1981	26.39	0.68	0.00	0.06	0.00	0.00	0.03	0.04	0.05
1982	30.99	0.35	0.00	0.05	0.00	0.00	0.03	0.03	0.01
1983	36.12	0.38	0.02	0.06	0.06	0.00	0.06	0.05	0.00
1984	34.71	0.32	0.00	0.09	0.09	0.01	0.03	0.04	0.00
1985	33.49	0.29	0.02	0.01	0.17	0.01	0.01	0.02	0.02
1986	32.90	2.23	0.13	0.32	0.31	0.10	0.09	0.10	0.02
1987	35.73	1.18	0.17	0.50	0.31	0.02	0.22	0.07	0.18
1978	123.24	0.84	0.01	0.20	0.02	0.00	0.02	0.03	0.01
1979	120.69	0.44	0.00	0.23	0.24	0.00	0.05	0.02	0.01
1980	122.16	0.35	0.02	0.24	0.02	0.00	0.01	0.03	0.01
1981	121.37	0.68	0.11	0.06	0.34	0.00	0.02	0.02	0.01
1982	119.50	0.38	0.00	0.01	0.10	0.28	0.02	0.01	0.00
1983	113.39	0.27	0.01	0.00	0.54	0.22	0.03	0.05	0.01
1984	115.58	0.54	0.01	0.06	0.48	0.16	0.03	0.02	0.00

year	Average farm size (ha)	maize	s/maize	tobacco	wheat	soybeans	s/cotton	s/flowers	potatos
1985	119.32	0.17	0.10	0.00	0.24	0.12	0.01	0.02	0.00
1986	125.04	0.29	0.01	0.07	0.38	0.12	0.02	0.01	0.01
1987	127.15	0.72	0.12	0.30	0.61	0.09	0.04	0.03	0.02
1978	276.41	0.39	0.00	0.13	0.08	0.00	0.01	0.00	0.02
1979	276.67	0.34	0.00	0.13	0.16	0.00	0.01	0.00	0.02
1980	278.14	0.44	0.00	0.11	0.17	0.00	0.01	0.00	0.01
1981	277.59	0.14	0.01	0.05	0.17	0.00	0.00	0.00	0.00
1982	269.37	0.50	0.01	0.16	0.06	0.00	0.02	0.01	0.01
1983	286.53	0.27	0.06	0.10	0.21	0.00	0.01	0.03	0.08
1984	284.37	0.36	0.27	0.09	0.39	0.00	0.14	0.01	0.12
1985	283.38	0.45	0.16	0.02	0.56	0.05	0.01	0.01	0.16
1986	267.05	0.38	0.11	0.03	0.32	0.03	0.02	0.01	0.01
1987	260.19	0.20	0.05	0.06	0.21	0.06	0.01	0.02	0.01
1978	557.36	0.61	0.04	0.11	0.04	0.00	0.01	0.00	0.00
1979	557.56	0.38	0.03	0.09	0.09	0.00	0.00	0.00	0.00
1980	576.82	0.76	0.05	0.08	0.30	0.00	0.01	0.00	0.00
1981	573.27	0.57	0.07	0.09	0.19	0.00	0.01	0.00	0.01

year	Average farm size (ha)	maize	s/maize	tobacco	wheat	soybeans	s/cotton	s/flowers	potatos
1982	567.78	0.45	0.03	0.01	0.02	0.04	0.00	0.00	0.01
1983	595.64	0.15	0.05	0.01	0.02	0.02	0.00	0.00	0.03
1984	606.04	0.36	0.01	0.01	0.03	0.06	0.00	0.00	0.02
1985	577.61	0.25	0.09	0.01	0.07	0.00	0.02	0.01	0.03
1986	577.08	0.20	0.72	0.00	0.15	0.20	0.00	0.00	0.05
1987	588.83	0.08	0.02	0.16	0.07	0.10	0.00	0.00	0.03
1978	1392.40	1.04	0.25	0.32	0.00	0.00	0.01	0.00	0.01
1979	1243.03	0.66	0.08	0.12	0.00	0.00	0.01	0.00	0.01
1980	1266.34	0.71	0.06	0.11	0.01	0.00	0.01	0.01	0.00
1981	1242.56	1.03	0.13	0.07	0.05	0.00	0.01	0.00	0.02
1982	1194.29	0.92	0.16	0.15	0.02	0.00	0.01	0.00	0.00
1983	1310.10	0.89	0.22	0.11	0.02	0.01	0.01	0.00	0.01
1984	1306.58	0.95	0.51	0.15	0.05	0.04	0.01	0.02	0.04
1985	1248.66	0.71	0.20	0.21	0.04	0.14	0.01	0.01	0.03
1986	1345.50	1.04	0.09	0.40	0.17	0.05	0.00	0.00	0.01
1987	1290.49	0.90	0.10	0.42	0.03	0.06	0.02	0.00	0.01
1978	4872.85	0.21	0.08	0.15	0.01	0.00	0.00	0.00	0.00
1979	5466.12	0.23	0.07	0.10	0.03	0.00	0.01	0.00	0.01
1980	6719.61	0.24	0.05	0.09	0.03	0.00	0.00	0.01	0.00

year	Average farm size (ha)	maize	s/maize	tobacco	wheat	soybeans	s/cotton	s/flowers	potatos
1981	4630.68	0.34	0.08	0.07	0.16	0.00	0.01	0.06	0.04
1982	4960.56	0.42	0.03	0.07	0.02	0.02	0.01	0.02	0.00
1983	6184.40	0.65	0.01	0.08	0.01	0.02	0.00	0.01	0.02
1984	7352.12	0.68	0.04	0.04	0.01	0.03	0.00	0.01	0.02
1985	8117.09	0.30	0.03	0.07	0.19	0.13	0.00	0.00	0.05
1986	6390.30	0.44	0.05	0.08	0.08	0.07	0.00	0.00	0.03
1987	6297.81	0.45	0.02	0.09	0.16	0.09	0.00	0.00	0.02

Appendix II: Calculated Elasticities

Year	Average area	wages	capital	output	land	rainfall
1978	34.14	1.80	0.79	0.65	1.90	1.05
1979	33.02	1.51	1.16	0.87	1.39	0.43
1980	28.14	1.60	0.43	0.70	1.69	-0.02
1981	26.39	1.73	0.24	0.77	1.47	1.18
1982	30.99	1.36	0.35	0.91	1.07	-1.24
1983	36.12	1.18	0.27	1.07	0.81	-2.00
1984	34.71	1.30	0.30	1.16	0.47	0.05
1985	33.49	1.34	0.22	1.56	0.08	1.12
1986	32.90	1.68	-0.54	1.44	0.02	0.86
1987	35.73	1.37	-0.66	1.49	-0.17	-1.78
1978	123.24	1.39	1.03	0.55	1.80	0.05
1979	120.69	1.11	1.11	0.74	1.46	-1.52
1980	122.16	0.97	1.15	0.82	1.12	-2.08
1981	121.37	1.18	1.01	0.74	0.96	0.52
1982	119.50	0.79	0.90	0.92	0.71	-2.98
1983	113.39	0.70	1.13	1.06	0.20	-2.82
1984	115.58	0.79	1.21	1.25	-0.17	-0.39
1985	119.32	0.78	1.06	1.39	-0.34	0.44
1986	125.04	1.32	-0.08	1.72	-0.41	1.23
1987	127.15	0.82	0.06	1.48	-0.55	-2.33

Year	Average area	wages	capital	output	land	rainfall
1978	276.41	1.23	1.23	0.14	1.89	0.98
1979	276.67	0.93	0.98	0.42	1.71	-2.01
1980	278.14	0.79	1.19	0.54	1.24	-1.98
1981	277.59	1.07	0.93	0.71	1.00	0.68
1982	269.37	0.79	0.73	0.72	0.82	-2.39
1983	286.53	0.57	0.52	0.91	0.71	-3.68
1984	284.37	0.67	0.62	1.02	0.28	-1.83
1985	283.38	0.70	0.73	1.15	-0.16	-0.65
1986	267.05	0.89	0.41	1.50	-0.50	0.46
1987	260.19	0.64	0.26	1.89	-0.90	-2.33
1978	557.36	1.35	1.09	1.03	1.12	-0.09
1979	557.56	0.98	1.18	1.32	0.75	-2.33
1980	576.82	1.09	0.87	1.02	0.79	-1.21
1981	573.27	1.07	0.83	1.24	0.48	-0.51
1982	567.78	0.66	0.89	1.44	0.14	-3.69
1983	595.64	0.54	0.76	1.46	-0.04	-4.18
1984	606.04	0.70	0.92	1.49	-0.45	-1.27
1985	577.61	0.86	0.71	1.35	-0.44	1.26
1986	577.08	0.76	0.83	1.26	-0.79	0.86
1987	588.83	0.42	0.48	1.46	-0.93	-3.13

Year	Average area	wages	capital	output	land	rainfall
1978	1392.40	1.38	1.12	0.65	0.99	0.12
1979	1243.03	1.19	1.02	0.82	0.82	-0.68
1980	1266.34	1.25	0.78	0.70	0.65	-0.58
1981	1242.56	1.29	0.74	0.77	0.36	0.36
1982	1194.29	1.02	0.83	0.89	0.01	-1.14
1983	1310.10	0.82	0.72	1.07	-0.28	-2.88
1984	1306.58	0.92	0.42	1.17	-0.34	-1.46
1985	1248.66	1.11	0.08	1.23	-0.47	0.00
1986	1345.50	1.09	0.31	1.01	-0.79	1.51
1987	1290.49	0.75	0.07	1.29	-1.03	-2.16
1978	4872.85	1.24	1.49	0.47	0.61	0.84
1979	5466.12	1.00	0.87	0.53	0.76	-2.25
1980	6719.61	1.01	1.03	0.37	0.37	-0.88
1981	4630.68	1.10	0.91	0.67	0.12	0.32
1982	4960.56	0.82	0.85	0.67	-0.07	-1.59
1983	6184.40	0.59	0.79	0.78	-0.41	-3.50
1984	7352.12	0.93	0.37	1.30	-0.86	-1.37
1985	8117.09	0.98	0.40	1.32	-1.19	0.18
1986	6390.30	1.04	0.24	1.55	-1.49	0.57
1987	6297.81	0.64	0.18	1.72	-1.77	-3.22

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