Measuring and Analysing Agricultural Productivity in Kenya: a Review of Approaches

Walter Odhiambo
Hezron O. Nyangito

Productive Sector Division
Kenya Institute for Public Policy
Research and Analysis

KIPPRA Discussion Paper No. 26
January 2003

KIPPRA IN BRIEF

The Kenya Institute for Public Policy Research and Analysis (KIPPRA) is an autonomous institute whose primary mission is to conduct public policy research, leading to policy advice. KIPPRA's mission is to produce consistently high-quality analysis of key issues of public policy and to contribute to the achievement of national long-term development objectives by positively influencing the decision-making process. These goals are met through effective dissemination of recommendations resulting from analysis and by training policy analysts in the public sector. KIPPRA therefore produces a body of well-researched and documented information on public policy, and in the process assists in formulating long-term strategic perspectives. KIPPRA serves as a centralized source from which the government and the private sector may obtain information and advice on public policy issues.

Published 2003

Bishops Garden Towers, Bishops Road
PO Box 56445, Nairobi, Kenya
tel: +254 2 2719933/4; fax: +254 2 2719951
email: **admin@kippra.or.ke**
website: http://www.kippra.org
ISBN 9966 949 46 1

The Discussion Paper Series disseminates results and reflections from ongoing research activities of the institute's programmes. The papers are internally refereed and are disseminated to inform and invoke debate on policy issues. Opinions expressed in the papers are entirely those of the author or authors and do not necessarily reflect the views of the Institute.

KIPPRA acknowledges generous support by the European Union (EU), the African Capacity Building Foundation (ACBF), the United States Agency for International Development (USAID), the Department for International Development of the United Kingdom (DfID) and the Government of Kenya (GoK).

ABSTRACT

Concern is rising about the performance of the agricultural sector in Kenya given that it is the backbone of the country's economy. The issue of particular concern is the declining productivity that has been associated with increasing poverty, food shortages and poor rural livelihoods. Although there have been attempts to analyse agricultural productivity in Kenya, a cursory examination of the existing studies reveals quite varied approaches to the measurement and analysis of productivity. Variability in the analytical methods and data employed make it difficult for policy makers, the Government, NGOs and even donors to interpret, compare and evaluate the results of such studies. The objective of this paper is to review studies that have attempted to empirically measure and analyse agricultural productivity in Kenya. The focus of the survey is on the approaches that have been used and their relevance in policy formulation. The major conclusion of the study is that although there have been attempts to analyse agricultural productivity in Kenya, the approaches, the data used, as well as the scope have largely been inadequate. This has hampered policy formulation for the development of agricultural productivity. The paper therefore identifies research gaps and proposes new directions in the measurement and analysis of agricultural productivity in Kenya.

ABBREVIATIONS

CBS	Central Bureau of Statistics (Kenya)
C-D	Cobb-Douglas
CES	Constant Elasticity Substitution
DEA	Data Enveloping Analysis
GLS	Generalized Least Squares
MLE	Maximum likelihood method
OLS	Ordinary Least Squares
PFT	Partial factor productivity
TFP	Total factor productivity
3SLS	Three-Stage Least Squares

TABLE OF CONTENTS

1. Introduction 1

2. Theoretical approaches of measuring agricultural productivity 3

- 2.1. Technical progress 4
- 2.2 Productivity growth 5
- 2.3 Efficiency 7
- 2.4 Total factor productivity 8
- 2.5 Measuring total factor productivity 9
  - 2.5.1 Approaches that ignore inefficiency 9
  - 2.5.2 Approaches that incorporate inefficiency 13

3. Review of agricultural productivity studies in Kenya 24

- 3.1 Empirical studies on productivity 24
  - 3.1.1 Macro studies 24
  - 3.1.2 Messo studies 27
  - 3.1.3 Micro studies 30
- 3.2 Empirical determinants of productivity 34
  - 3.2.1 Resources inputs 34
  - 3.2.2 Fertilizer use 35
  - 3.2.3 Market access and orientation 36
  - 3.2.4 Extension services 37
  - 3.2.5 Farm size 38
  - 3.2.6 Biophysical factors 38
  - 3.2.7 Land tenure 39

4. Evaluation of previous work and new directions in empirical research 40

- 4.1. Average versus marginal productivity indicators 40
- 4.2 Use of alternative models 41
- 4.3 Model specification 42
- 4.4 Issues of resource use efficiency 42
- 4.5 Environmental impact 43
- 4.6 Effects of transaction costs 44
- 4.7 Data types and sources 45

5. Conclusions and implications for further research 47

References 49

1. Introduction

The improvement of agricultural productivity has attracted the attention of policy makers, researchers and development practitioners in Kenya for two main reasons. First, Kenya relies heavily on agriculture for economic growth, export earnings, and employment generation. The agricultural sector employs 70% of the Kenyan labour force, generates 60% of the foreign exchange, provides 75% of raw materials for industry, and provides about 45% of total Government revenue. Besides, the sector is the growth engine for the non-agricultural sector with a multiplier effect of about 1.64. Second, indications in Kenya, and in many other sub-Saharan African countries, are that agriculture is becoming progressively less productive. A declining trend in both labour and land productivity constitutes a major challenge and portends lower living standards in the farm sector and the rest of the economy.

Literature in Kenya and in other developing countries is abound with discussions of factors considered to be important in determining agricultural productivity. These include quantifiable factors such as technical change, relative factor product prices, input use, education, agricultural research and extension, market access and availability of credit. Other factors include weather, farm production policies, land ownership patterns, inadequate involvement of beneficiaries in decision-making, insecurity and the legal and regulatory environment. Many development programs and projects in Kenya have attempted to remove constraints associated with these factors by introducing facilities to provide credit, information, farm inputs, infrastructure, education, marketing networks, etc. The removal of these constraints, it is believed, can result in increased productivity at farm level and also an increase in farm incomes. This is important for alleviating poverty, increasing household food security, and stimulating growth in non-farm activities in Kenya. Indeed, declining agricultural productivity has been identified as a major cause of poverty in Kenya. According to the Kenya Poverty

Reduction Strategy Paper (PRSP), declining agricultural productivity has led to food shortages, underemployment, low incomes from cash crops and poor nutritional status which further reduces labour productivity (Republic of Kenya, 2001).

Assessing the overall impact of interventions in agriculture and reversing the declining trend in productivity requires accurate measurement of the effects of alternative courses of action, a task that raises conceptual and methodological issues. A cursory examination of the literature on productivity in the country reveals quite varied measurement and analytical approaches. Variability in the analytical methods and data used make it difficult for policy makers, NGOs, and even donors to interpret, compare and evaluate the results of productivity studies. This has led to differing conclusions, which have sometimes conflicted. Another issue of concern is that writings on various aspects of agricultural productivity are either too old and need regular updating or are scattered through a wide variety of sources in the country. As the Government implements new agricultural policies and programs aimed at increasing overall productivity, it is important that it accesses accurate agricultural data and analyses. Poor agricultural data and analyses can lead to misallocation of scarce resources and formulation of policies that fail to resolve critical challenges in the sector.

The purpose of this paper is to survey various studies that have attempted to measure and analyse agricultural productivity in Kenya. The focus of the survey is on the strengths and weaknesses of the different approaches that have been used to measure and analyse agricultural productivity. Because of the diversity of such published work, an attempt is made to simply review representative works rather than present an exhaustive discussion of all that has been done. The next section introduces a number of key concepts and the conceptual framework for measuring and analysing agricultural productivity. Section three presents a review of empirical approaches and results of studies on agricultural productivity in Kenya. Section four takes a critical look at the approaches, the data used, and the conclusions of the empirical studies of agricultural productivity in Kenya. The conclusions and implications for further research and analysis are presented in the last section.

2. Theoretical Approaches of Measuring Agricultural Productivity

The aim of this section is to review the theoretical approaches for measuring agricultural productivity in the wider literature. The section first gives the definition of key concepts, namely technical progress, productivity growth and efficiency. This is necessary in providing a common understanding of the usage of these terms in analysis of agricultural productivity. The section then looks at the theoretical approaches and methodologies used in the literature to measure agricultural productivity.

Before defining key concepts in productivity analysis, it is important to note at the outset that works on agricultural productivity can be broadly classified into two groups: theoretical and empirical. Theoretical studies define productivity and its determinants more rigorously and set precise relationships for estimation. They also suggest hypotheses that can be tested empirically. Empirical studies on the other hand examine trends over time and quantify the contributions of specific inputs, policies, technologies and other productivity-enhancing factors. In the realm of empirical studies, Kelly *et al* (1995), in a similar survey to this one, identify three categories of productivity work in agriculture. These are "macro", "messo" and "micro" studies. Macro studies use time series data reported at the national level, while messo studies use national data disaggregated into farm types (large or small), agro-ecological zones, or administrative regions. Micro studies use cross-sectional data, which permit comparison across different sub-groups at a particular point in time. This review is organized around this broad categorization. While this section examines the theoretical underpinnings of productivity, the next section reviews empirical micro, messo and macro studies on agricultural productivity in Kenya.

2.1 Technical Progress

Methods of production change over time and it is important to be able capture the effects of such changes on output. Capturing such effects can ideally be done within the production function framework. Starting of with a simple production relationship in which output depends on capital input K, and labour L, the production function can be expressed as:

$$Q=f(K, L) \qquad (1)$$

where Q (the output) depends on how much of K and L is used. If the levels of K and L are increased/reduced, then it is expected that Q will also correspondingly increase/decrease. However, Q can also increase by using the same level of K and L. This is possible if a superior technology is used in the production process. However, output growth can also be attributed to other factors other than growth in the conventionally defined inputs. When this is the case, then technical progress has taken place. In terms of the production relations, such a change represents a shift in the production frontier and can be defined as:

$$Q=A(t)f(K, L) \qquad (2)$$

where A(t) represents all the influences that go into determining Q besides K and L. Changes in A over time represent technical progress. It is important to note that technical change may influence output in two distinct ways. First, technical change may influence output by affecting not a single input but all the inputs. This would be a case of neutral technical progress or disembodied technical progress. Equation (1) above is a case of neutral technical progress. The second case is where technical change affects output by augmenting either capital (capital-augmenting technical progress) or labour (labour-augmenting technical progress). These two cases are commonly referred to as disembodied technical progress and can be represented as:

$$Q = f[A(t)K, L] \qquad (3)$$

and

$$Q = f[K, A(t)L] \qquad (4)$$

Equation (3) represents the capital-augmenting technical progress while equation (4) is a case of labour-augmenting technical progress. In all the three cases represented by equations (2)-(4), the empirical question is how to measure A(t).

2.2 Productivity Growth

The concept of technical progress is closely related to productivity growth. In fact, productivity growth has been shown to be a major source of growth of aggregate output (Solow, 1957) and of agricultural output (Hayami and Ruttan, 1985). Hayami and Ruttan (1985) have shown that agricultural output can grow in two main ways: an increase in use of resources of land, labour, capital and intermediate inputs or through advances in techniques of production through which greater output is achieved through a constant or declining resource base. This relationship is shown in Table 1. The latter, also referred to as productivity, occurs without a corresponding change in output, occasioning a rise in the ratio of total outputs to inputs. Seen in this way, productivity can be defined simply as a measure of the increase in output that is not accounted for by the growth of production inputs. Under certain assumptions of efficiency, productivity growth and technical change are synonymous (Grosskopf, 1993).

Table 1: Sources of agricultural outputs

Changes in agricultural outputs

Conventional market measured outputs	Non-market adjustments *(when estimates available)*
Crops	Natural resource depletion
Livestock	Environmental degradation

=

Changes in agricultural inputs

Conventional market measured inputs adjusted for quality

Intermediate
- Fertilizers
- Pesticides
- Energy
- Feed and seed
- Livestock

Labour

Capital
- Equipment
- Real estate
- Inventories

\+

Agricultural productivity growth

(Change of output not accounted for by change in inputs)

Sources are:
- Agricultural research and development
- Extension
- Education
- Infrastructure
- Government

Conventionally, productivity is measured by an index of output divided by inputs. Two measures of productivity are frequently used: the partial factor productivity (PFP) and total factor productivity (TFP). PFP is simply the ratio of output and any one of the inputs, typically labour or land. In notation form this can be expressed as:

$$PFP = Y/X_i \qquad (5)$$

where Y is output and X is input i. Although commonly used, the partial productivity measure has one important weakness in that it does not control for the level of other inputs employed. TFP on the other hand measures output per unit of total factor inputs. Therefore, total factor productivity is a generalization of single factor productivity measures such as land productivity or labour productivity.

2.3 Efficiency

The concept of technical efficiency entails a comparison between observed and optimal values of output and inputs of a production unit (Sadoulet and Janvry, 1995). This comparison takes the form of the ratio of observed to maximum potential output obtainable from the given input, or the ratio of the minimum potential to observed input required to produce the given output, or some combination of the two. These two give rise to the concepts of technical and allocative efficiency. A productive entity is technically inefficient when, given its use of inputs, it is not producing the maximum output possible (output distance), or given its output, it is using more inputs than is necessary. Similarly, a production unit is allocatively inefficient when it is not using the combination of inputs that would minimise the cost of producing a given level of output (Sadoulet and Janvry, 1995).

Efficiency and productivity are closely related. Changes in productivity are due to differences in production technology, differences in the efficiency of the production process, and differences in the environment in which production takes place (Grosskopf, 1993). Productive efficiency is therefore an important determinant of productivity and should be incorporated in productivity analyses. The empirical challenge is to measure productive efficiency and to apportion its share in the productivity variations.

2.4 Total Factor Productivity

As already indicated, most analyses of agricultural productivity have utilised the TFP concept. Because of its superiority over other measures of productivity, TFP is examined in some detail in this sub-section. Grosskopf (1993) outlines the basic procedure for deriving the TFP index. Considering two time periods *t* and *t+1*, corresponding outputs and inputs denoted by y^t and y^{t+1} and x^t and x^{t+1}, the production transformation model S^t, for period *t* can be expressed as:

$$S^t = \{(x^t, y^t): x^t \text{ can produce } y^t\} \quad (6)$$

Similarly for S^{t+1}

$$S^{t+1} = \{(xt^{+1}, y^{t+1}): x^{t+1} \text{ can produce } y^{t+1}\} \quad (7)$$

The set *S* describes all the feasible input-output pairs at a given point in time. In a similar manner, technology can also be described with a production function in period *t* as

$$y^t = \max\{y'^t : (x^t, y'^t) \, \varepsilon \, S^t\} \quad (8)$$

and in period *t+1*

$$y^{t+1} = \max\{y'^{t+1} : (x^{t+1}, y'^{t+1}) \, \varepsilon \, S^{t+1}\} \quad (9)$$

Assuming neutral disembodied technology in the Hicksian sense (that is technology independent of input) the production functions in the two periods can be denoted by:

$$y^t = A(t)f(x^t)$$

$$y^{t+1} = A(t+1)f(x^{t+1}) \qquad (10)$$

where A is a technology shift parameter.

Based on equation (10), total factor productivity (TFP) can be defined for the two periods as:

$$TFP(t) = y^t/f(x^t) = A(t)$$

$$TFP(t+1) = y^{t+1}/f(x^{t+1}) = A(t+1) \qquad (11)$$

The total factor productivity growth can then be defined as the change in total factor productivity between period t and t+1, that is:

$$TFP(t+1)/TFP(t) = A(t+1)/A(t) \qquad (12)$$

It needs to be noted here that technical change and productivity growth are synonymous in the special case when production is technically efficient (Grosskopf, 1993).

2.5 Measuring Total Factor Productivity

As stated earlier, the empirical challenge is to estimate A(t) in equation (12). In the literature there are two different approaches of doing this. The major difference in the approaches is the assumption made about technical efficiency. Traditional approaches of measuring productivity assume that output is technically efficient and that production is taking place at the frontier of the production. Recent approaches allow for inefficiency. The following subsection reviews these two broad approaches to the estimation of TFP.

2.5.1 Approaches that ignore inefficiency

Non-parametric approaches

Until very recently, models of productivity have ignored efficiency as a determinant of productivity. Solow (1957) sought to attribute output growth to input growth and technical change by distinguishing movements along a production frontier from shifts in the frontier. From a production function of the form shown in equation (8), Grosskopf (1993) postulates the decomposed Solow model to be of the form:

$$\frac{\dot{A}}{A} = \frac{\dot{y}}{y} - \sum_{n-1}^{N} S_n \left(\frac{\dot{x}_n}{x_n} \right) \quad \text{..(13)}$$

where the dots indicate time derivatives and s_n is the elasticity of output with respect to inputs. Equation (13) gives the accounting definition of productivity as the residual growth in output not accounted for by growth in input. This definition is associated to Solow (1957), Denison (1972), Kendrick (1961) and Jorgenson and Griliches (1967).

To compute equation (13), Solow made the assumption that the time derivatives could be approximated by discrete changes. This assumption results in a non-parametric growth index equivalent to the Divisia Index of productivity growth. Grosskopf (1993) shows that if the continuous growth rates in equation (13) above are replaced by the discrete difference in the logarithms (i.e. $y'/y = \ln y^{t+1} - \ln y^{t}$) and the input shares as arithmetic means, the index becomes equivalent to the Tornqvist (1936) index (π) of total factor productivity growth, which takes the form (the variables are as defined before):

$$\mathrm{LnT_1} = \ln y^{t+1} - \ln y^{t} - \sum_{n-1}^{N} \frac{1}{2} \left[S_n(t+1) + S_n(t) \right] \left(\ln x_n^{t+1} - \ln x_n^{t} \right) \quad \text{...........(14)}$$

The Tornqvist index has been widely used to calculate the annual index of TFP. The index can either be a price or quantity index. It has one advantage in that it is simple and easy to compute. This is because there are no parameters to be estimated in the model. The only weakness with the index is that it does not account for measurement or sampling errors. As such, it leaves out departures from efficient production due to measurement errors (noise) or technical inefficiency.

Econometric approaches

The econometric approach is often the alternative to the non-parametric index approach. The approach involves parametizing the production function and estimating its parameters. This would take the form of

$$y^t = f(x^t, t) + \varepsilon \qquad (15)$$

for t=1, 2….T and where ε is intended to capture the effect of stochastic noise. The estimated parameters from the model can then be used to solve for technical change in the model. In the absence of technical inefficiency, the technical change will be the TFP and will be reflected in the vertical shifts in the production function; that is by increases in output that are not accounted for in increases in use of inputs. Mathematically, TFP can be computed as the difference between output and weighted average of the inputs. The weights are estimated econometrically from the production coefficients in the agricultural production functions. Using a Cobb-Douglas production function with capital K and labour L, Block (1994) estimated TFP as:

$$TFP = \log Y - \beta_1 \log K - \beta_2 \log L \qquad (16)$$

where Y is output and β_1 and β_2 are parameters. In computing agricultural productivity, Equation (16) can be expanded to include other factor inputs that determine productivity, such as land and fertilizers.

The duality relationship between the production function and the cost function has also been used to estimate TFP. The duality hypothesis stipulates that for every production function, there is a dual cost function relating factor prices to the cost of output. The dual cost function contains all the information that the production function contains (Varian, 1992). Biswanger (1974) has shown the cost function to be more desirable for econometric analysis than the production function for a variety of reasons. First, that by using the cost function approach, the problem of endogeneity in factor levels is eliminated since factor prices and output levels are exogenous. Second, that the cost function approach reduces the problem of multi-collinearity since less multi-collinearity exists among factor prices than factor quantities. Third, the approach yields direct estimates of the various elasticities of substitution. It is worth noting at this point that this approach involves the estimation of the cost function along with the input demand functions derived from the Hotellings lemma. The duality approach does not however explicitly take efficiency issues into consideration. In other words it is not possible to isolate the efficiency effects from other effects using this approach.

The dual approach in the analysis of productivity and efficiency can be demonstrated by considering both the Cobb-Douglas (C-D) and the constant elasticity of substitution (CES) production functions which are the most widely used forms. Equations (17) and (18) depict the C-D and CES production functions.

$$Y = \gamma x_1^{\alpha} x_2^{\beta} \qquad (17)$$

where $\beta=1-\alpha$, and

$$Y=\lambda(\delta x_1^{-\rho}+(1-\delta)x_2^{-\rho})^{-v/\rho} \qquad (18)$$

where λ, ρ, δ and v are efficiency, distribution and substitution parameters. Given that $C=r_1x_1=r_2x_2$ is the corresponding dual cost function for the C-D and CES production functions are:

$$C = \left(\frac{Y}{\lambda}\right)^{v\frac{1}{}} \left[r1\left(\frac{\beta}{\alpha^{\frac{r1}{r2}}}\right)^{\frac{-\beta}{v}} r2\left(\frac{\alpha}{\beta^{\frac{r2}{r1}}}\right)^{\frac{-\alpha}{v}} \right] \qquad (19)$$

where $v=\alpha+\beta$ and

$$C = \frac{Y^{\frac{-1}{v}}}{\gamma} [\delta^{\sigma} r1^{1-\sigma} (1-\delta) r^{1-\sigma}]^{\frac{1}{1-\sigma}} \qquad (20)$$

where σ=1/1+ρ is the elasticity of substitution. Based on these costs functions, the conditional input demand functions can be generated for both the C-D and the CES cost functions as:

$$X_j = \left(\frac{\alpha}{r_i}\right)^{1-\frac{\beta}{\gamma}} \left(\frac{\beta}{r_j}\right)^{\frac{\beta}{\lambda}} (\gamma\rho)^{\frac{1}{\lambda}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(21)$$

and

$$X_i = \left(\frac{Y}{\lambda}\right)^{\frac{1}{v}} ri^{-\sigma}(1-\sigma)^{\sigma}[\delta^{\sigma} r_j^{1-\sigma} + (1-\delta)^{\sigma} r_i^{1-\sigma}]^{\frac{1}{\rho}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(22)$$

where λ=1-α-β. The C-D production function restricts the elasticity of substitution to unity while the CES production function imposes constancy of elasticity of substitution. In this approach, the cost function is estimated alongside the input demand functions and its parameters used as indicators of productivity and efficiency as already outlined.

2.5.2 Approaches that incorporate inefficiency

Admittedly, works on approaches that explicitly incorporate efficiency in productivity analysis are quite recent. They too can be divided into parametric and non-parametric.

Non-parametric approaches

These include approaches that use indices in measuring productivity growth. Two of the most widely used are the Malmquist-type-type of indices and the Data Enveloping Analysis.

(i) Malmquist-type indices

This approach is based on the Malmquist-type index, which explicitly allows for inefficiency. The index is constructed from distance functions, which make it easier to calculate and isolate changes in efficiency.

According to the pioneers of this approach, Fare, Grosskopf, Lindgren, and Roos (1989), the approach does not require price or share data, therefore allowing applications where outputs and inputs may not be marketed.

To demonstrate the Malmquist Index, Grosskopf (1993) assumes for each period t =1, ...T, the existence of a production technology S^t model that transforms inputs x^t into outputs y^t. It assumes further that S^t is sufficiently regular to define meaningful output distance functions. The distance with respect to two different time periods are:

$$D^t_o(x^{t+1}, y^{t+1}) + \inf\{\theta: (x^{t+1}, y^{t+1}/\theta) \varepsilon S^t\} \text{.....................(23)}$$

and

$$D^{t+1}_o(x^t, y^t) + \inf\{\theta: (x^t, y^t/\theta) \varepsilon S^{t+1}\} \text{.......................(24)}$$

The first distance function in equation (23) measures the maximum proportionate change in outputs required to make (x^{t+1}, y^{t+1}) feasible in relation to the technology at the previous period t. Similarly, equation (24) measures the maximum proportional change in output required to make (x^t, y^t) feasible in relation to the technology at t+1. Based on these, an output based Malmquist productivity can be defined as:

$$M^t_o = D^t_o(x^{t+1}, y^{t+1})/(D^t_o(x^t, y^t) \text{ ....(25)}$$

and

$$M^{t+1}_o = D^{t+1}_o(x^{t+1}, y^{t+1})/(D^t_o(x^t, y^t) \text{.................................(26)}$$

The Malmquist index can then, according to Fare, Grosskopf, Lindgren and Roos (1989), be arrived at by taking the geometric mean of the two-output based indices in equation (25) and (26) as:

$$M_0(x^{t+1}, y^{t+1}, x^{t1}, y^t) = \left[\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \right]^{\frac{1}{2}} \text{ ....(27)}$$

Equation 27 can also be re-written as:

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_9^{t}(x^{t}, y^{t})}\left[\frac{D_o(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})}\frac{D_o^{t}(x^{t}, y^{t})}{D_o^{t+1}(x^{t}, y^{t})}\right]^{\frac{1}{2}} \quad \text{........(28)}$$

Based on equation (23), the efficiency change (EC) and the technical change (TC) can be expressed as:

$$EC = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t}(x^{t}, y^{t})} \quad \text{...(29)}$$

and

$$TC = \left[\frac{D_0^{t+1}(x^{t+1}, y^{t+1})D_0^{t}(x^{t}, y^{t})}{D^{t+1}(x^{t+1}, y^{t+1})D_0^{t+1}(x^{t}, y^{t})}\right]^{1/2} \quad \text{.............................(30)}$$

(ii) Data Enveloping Analysis

Recent mathematical programming approaches in the measurement of productive efficiency have mainly taken the form of data enveloping analysis (DEA). This approach is commonly used to evaluate the efficiency of a number of producers. Unlike other statistical procedures that evaluate each producer relative to the average producer, DEA compares each producer with only the "best" producers. The fundamental assumption here is that if a given producer A is capable of producing output Y(A) with X(A) inputs, then other producers should be able to do the same if they were to operate efficiently. Similarly, if a producer B is capable of producing Y(B) units of output with X(B) inputs, then other producers should also be capable of the same production schedule. Producer A, B and others can then be combined to form a composite producer with composite inputs and composite outputs. Since this composite producer does not necessarily exist, it is sometimes called the virtual producer.

The gist of the analysis in DEA is finding the best virtual producer for each real producer. If the virtual producer is better than the original producer by either making more output with the same inputs or making the same output with less input, then the original producer is inefficient (Lovell, 1993). The procedure of finding the best virtual producer can be formulated as a linear program. Analysing the efficiency of n producers is then a set of n linear programming problems. The programming approach, like the econometric one, can be categorized according to the type of data used (cross-section or panel) and according to the type variables (quantities only or quantities and prices). While it is possible to measure technical efficiency with quantities only, it is necessary to have both prices and quantities to measure economic efficiency. Lovell (1993) provides a very good review of the mathematical programming approaches to the measurement of efficiency.

DEA has a number of advantages over the other measures of efficiency.

(i) DEA can handle multiple input and multiple output models.

(ii) Unlike the econometric approaches, DEA does not require an assumption of a functional form relating inputs to outputs.

(iii) DEA can handle inputs and output in different units. It can handle both quantities and prices measured in different units.

DEA is also associated with a number of weaknesses:

(i) Since DEA is an extreme point technique, its results are very sensitive to noise (even symmetrical noise with zero mean).

(ii) Since DEA is a non-parametric technique, statistical hypotheses tests are difficult.

(iii) Where a large number of producers are involved, DEA can be computationally intensive.

It is important to note that the application of DEA in agriculture has for reasons related to data been very limited. DEA has been applied in situations such as healthcare (hospitals, doctors), education, banks, manufacturing, management evaluation, fast foods restaurants and retail stores.

Parametric approaches

The concept of efficiency as earlier defined relates to how inputs are effectively used to produce a given output. Maximum efficiency is achieved when the most efficient production function is used and when the marginal value product of each factor on the production function is equal to its price. Efficiency, whether technical, allocative, or economic can be measured using a number of approaches which essentially involve the measurement of the frontier production function (Sadoulet and Janvry, 1995). These are:

(i) Engineering approaches

This approach involves assembling data from experimental fields and estimating the best production available and the production function currently in use. The production function to be estimated could take the form:

$$Q = f(x, Z_f, Z_p) \quad (31)$$

Where x represents factors used in production (land, fertilizer, seeds, insecticides, etc.), Z_f are the variables that characterize the particular farm's environment and Z_p are dummies which earmark the use of best practices (use of quality seeds, soil conservation, weed control, etc.). Two sets of estimates are then obtained from equation (31) above. The first is the yield estimate specific to the firm f_i (when Z_p is set to actual practice) and f_2 (where Z_p is set to actual practice values). The farmer-specific efficiency measure is then the difference between the two measures. The farmer-specific efficiency measure can then be regressed econometrically against a set of exogenous variables that characterize the farmer's circumstances. This approach has been used in a number of studies, the best example being that by Herdt and Mandac, 1981 in Philippines. In Kenya, the approach is mainly used in agricultural research stations and increasingly on on-farm research. Its results usually form the basis of input use recommendations by agricultural research institutions.

This approach has a number of advantages that make it appealing in the assessment of efficiency in agriculture (Sadoulet and Janvry, 1995):

(i) The approach is simple and straightforward. Its results are also very easy to interpret.

(ii) The data required for this analysis is directly generated from the experiments, and are likely to be more accurate than data collected by other means.

(iii) The approach generates a good indicator of efficiency that incorporates and reflects on technical changes associated with different methods of production, technologies, etc.

(ii) Use of average production functions

This is a particularly useful method of measuring differences in technical and allocative efficiencies between different categories of farms (e.g. small and large), different regions, and over time. The approach involves the estimation of a production function with farm, regional or time dummies included in the function. The dummies in the functions are meant to capture allocative and technical efficiency differentials. Yotopoulos and Lau (1973) provide a good example of this approach for estimating efficiency. In their analysis, the two authors specify and estimate a Cobb-Douglas production and profit functions of the form:

$$Q = ax^{\alpha}z^{\beta} \qquad (32)$$

and

$$\pi = a^{*}z^{\beta^{*}}p^{1-\alpha^{*}}w^{\alpha^{*}} \qquad (33)$$

Where x is labour used in production with corresponding wage w, z is a fixed factor, q is output with corresponding price q, and π is profit.

The other variables, namely α and β and *a* are parameters[1]. Based on these, Yotopoulos and Lau (1973) formulated and estimated the model below using time series data:

$$\text{Ln } \pi = \ln a^* + \delta_l D_l + £^{*\prime}{}_t D_t + \alpha^* \ln w + (1-\alpha^*) \ln p + £\beta^*{}_m \ln z_m$$

$$-wx/\pi = \lambda_l D_l + \lambda_s D_s \ldots\ldots\ldots\ldots (34)$$

where D_l, D_s, and D_t are dummies for large farms, small farms and time. The relevant estimation procedure here is the Zellner seemingly unrelated regression method. This approach requires data on the inputs used, prices, and profits disaggregated by type of farm or region. The obvious advantage of this approach is that it accounts for differences in efficiency between different categories of producers or regions. As already indicated, there are marked differences in terms of resource use and style of production between large and smallscale. There are at the same time significant regional differences in agricultural potentiality and efficiency. The main weakness of the approach has to do with the use of the production functions in estimation of efficiency. The first issue is which between the Cobb-Douglas and the CES (or indeed any other form) is the most appropriate functional form of the production function. The second issue has to do with the assumptions made in each case. The Cobb-Douglas production function restricts the elasticity of substitution to unity while the CES production function imposes constancy of elasticity of substitution. These are not particularly realistic assumptions in the context of agricultural production.

(iii) Stochastic frontier analysis

The use of econometric techniques in estimation of efficiency has increased considerably in recent times. This has mainly taken the form of estimating a frontier production function. Econometric approaches

[1] It can be shown that $a^* = a^{1/1-\alpha} \alpha^{\alpha/1-\alpha}$, $\beta^* = \beta/1-\beta$ and $\alpha^* = -\alpha/1-\alpha$

developed by Aigner, Lovell and Schmidt (1977) are among the first to use non-stochastic frontier methods of estimation. Since then, there have been several attempts to use the technique. These attempts vary according to the type of data used (cross-section or panel), the type of variables (quantities only, or quantities and prices) and the number of equations in the model.

(a) Cross-sectional designs

These are by far the most widely used techniques in the estimation of productive efficiency. The process involves the specification and estimation of a production function of the form:

$$Y_i = f(x_i, \beta) \exp \{v_i + u_i) \qquad (35)$$

where β is a vector of technology parameter, x are the inputs used and i=1….I indexes producers. The model specifies two random disturbance terms v_i and u_i. The random disturbance term v_i is intended to capture the effects of the stochastic noise. It is assumed to be independently distributed with a mean equal to zero and standard deviation equal to σ^2_v. The disturbance term u_i captures technical inefficiency and is assumed to be independent of v_i. Lovell (1993) shows that the technical efficiency (TE) can be expressed as a reciprocal of the Dubreau-Farrel output oriented technical efficiency. This can be written as:

$$TE_i = \frac{y_i}{[f(x_i;\beta) exp\{v_i\}]} = \exp\{u_i\} \qquad (36)$$

Estimation of technical efficiency was first accomplished by Aigner, Lovell and Schmidt (1977), Battese and Corra (1977) and Meeusen and Van den Broeck (1977). These studies provide estimates of the average technical efficiency over all the observations. The data used was cross-sectional in nature. To estimate the equations, a number of assumptions are necessary. First, it can be assumed that v_i=0 and then estimate a deterministic production frontier. The maximum likelihood method (MLE) can then be used as an estimation procedure in this case. The second assumption will be to assume that $v_i \neq 0$ and estimate a stochastic production frontier. MLE can also be used in this particular case.

It should be noted that the models above are single–equation models and would require the use of single equation techniques. However, it is also possible to specify and estimate multiple equation models. This is usually more appropriate in order to go around the weaknesses of single equations. By assuming profit maximization behaviour, this approach can be used to yield consistent and efficient estimates of economic efficiency. The approach essentially involves the estimation of a production frontier and the first order conditions for profit maximization. Starting from a typical production relationship of the form (Sadoulet and Janvry, 1995):

$$q^* = f(x) \qquad (37)$$

where q* is the maximum output a firm/producer could reach by using the inputs in a technically efficient manner. If the producer is not technically efficient, the predicted level of output with the observed level of inputs will be:

$$q = f(x)\, e^{u},\ u \leq 0 \qquad (38)$$

where e^u is the producer-specific technical efficiency parameter. If the firm is maximally efficient, u=0. If the producer is technically inefficient, $u<0$ and $q<q^*$. In the collection of data, measurement errors are in most cases unavoidable and the observed level of q will therefore depend both on the technical error term u, and v which captures noise.

$$q = f(x)e^{u+v},\ E(v)=0 \qquad (39)$$

If we then assume that producers are profit maximizers, then both the output and input levels are endogenous. This has the implication that both of these functions must be estimated simultaneously. According to Sadoulet and Janvry (1995), the system of equation to be estimated is:

$$\text{Ln q} = \alpha + \sum_{1=1}^{m} \beta_i \ln x_i + \frac{1}{2} \sum_{i=1}^{m} \sum_{j=1}^{m} \gamma_{ij} \ln x_j + u + v$$

$$C_i = \beta_i + \sum_{j=1}^{m} \gamma_{ij} \ln x_j + w_j , i = 1.....,m \qquad \text{...............................(40)}$$

where C_i is the share of the factor I in total revenue, calculated as $p_i x_i / pq$. This model can be estimated using the maximum likelihood approach.

Cross-sectional analyses of efficiency by their very nature provide a snapshot of the situation at only one particular point in time. The use of such a technique is associated with a number of advantages:

(i) It is possible to include many variables in the analysis as the data is obtained from a large number of subjects (in this case farmers).

(ii) The technique also allows for collection of data on attitudes and behaviours that may have a bearing on efficiency.

(iii) The technique also allows for the analysis of dispersed subjects, in this case farmers, in different regions or of different sizes.

Cross-sectional techniques of efficiency analysis however have a number of disadvantages:

(i) Cross-sectional data are typically more difficult to collect and are associated with increased chances of error.

(ii) The techniques are typically more expensive as they cover more subjects and areas.

(iii) Cross-sectional techniques cannot measure changes, particularly technological changes, that are a key determinants of efficiency.

(iv) The approach is static and time bound.

(b) Panel data designs

Panel designs collect repeated measurements from the same people or subjects over time. Panel data can also be used in estimation of frontier production functions. Using this kind of data, Schmidt and Sickles (1984) specified and estimated a production frontier model in the form:

$$Y_{it} = f(x_{it,} \beta) \exp \{v_{it}+u_i\} \qquad (41)$$

where t=1,…..T represents the different time periods, v_{it} is the noise time which varies over producers and time, and u_i is technical inefficiency. Technical efficiency will vary only over producers and not over time. The variation is as a result of the fact that each producer is observed more than once. Both the GLS and the maximum likelihood method can be used to estimate equation (41) above under certain specific assumptions. The GLS method assumes that u_i are uncorrelated while MLE will require distributional and independence assumptions. Examples of studies that have used panel data to analyse efficiency in agriculture include Dawson and Lingard (1991), Battese and Coelli (1998), Lundvall and Battese (1998) and Battese and Broca (1996).

The most important advantage of using panel data is that it may lead to better efficiency estimates as each producer is observed more than once over a period of time. The other advantage of using panel data models is that they are more capable of capturing the complexity of human behaviour as compared to cross-sectional or time series data models. They can reveal individual level changes and can show how relationships emerge. The approach is however associated with a number of disadvantages mainly in the collection of data. First, it is usually difficult to obtain initial samples of the subject. Second, once the samples have been found, it is difficult and costly to keep the same subjects over time. Thirdly, repeated measures being taken over the same subject may influence the subject's behaviour and therefore not yield reliable results.

3. Review of Agricultural Productivity Studies in Kenya

Having reviewed empirical and theoretical approaches entrenched in the wider literature, this section focuses on studies that have been done in Kenya. The aim is to delineate the approaches used in the analysis, spell out their strengths and weaknesses, and examine the nature and quality of data sets used. Studies on agricultural productivity in Kenya can broadly be classified into two categories: empirical and descriptive. Empirical studies are those that in one way or the other attempt some measurement of productivity. Descriptive studies on the other hand identify and discuss factors associated with agricultural productivity without necessarily providing empirical evidence. This review focuses more on empirical studies of measuring agricultural productivity.

3.1 Empirical Studies on Productivity

Empirical studies on productivity in Kenya have generally attempted to provide evidence on the relative importance of different productivity determining factors and to assess trends regionally and over time. While most of them are at the macro level, some are micro and messo. Table 2 is a summary of some of the empirical studies on productivity in Kenya.

3.1.1 Macro studies

Two studies that attempt an estimation of agricultural productivity in Kenya at a macro level are Block (1992) and Block and Timmer (1994). In these studies, agricultural TFP is defined as the difference between output and a weighted average of the inputs. Given a typical Cobb-

Table 2: Studies on agricultural productivity in Kenya

Author	Scope/data	Measure of productivity	Analytical focus	Type of analysis
1. Block and Timmer (1994)	Macro	Total factor productivity (TFP)	Estimating the TFP for agriculture and linking it to non-agricultural TFP	Parametric
2. Block (1992)	Macro	Total factor productivity	Trend over time	Parametric
3. Nyariki and Thirtle (2000)	Micro	Malmquist productivity index	Determinants of agricultural productivity	Non-parametric
4. Owuor, J (1999)	Micro	Partial factor productivity (PFP) -land and labour	Analysis of determinants of productivity	Parametric
5. Nyoro and Jayne (1999)	Messo	Partial factor productivity (PFP –land and labour	Trend analysis-regional and over time	Parametric
6. Evenson and Mwabu (1998)	Micro	Crop yield per acre	Measure the effect of extension controlling for other determinants of productivity Analysis of determinants	Parametric/econometric
7. Ekborm (1998)	Micro	Crop yield weighted by farm area and crop price	Analysis of trends	Parametric
8. Njue and Fox (1993)	Macro	Multi factor productivity index	Analysis of determinants	Non-parametric
9. Strasberg, Jayne, Yamano, Nyoro, Karanja, Strauss (1999)	Micro	Value of output per acre	Analysis of determinants	
10. Migot-Adholla, Place & Oluoch-Kosura (1994)	Micro	Plot/parcel yield Value of output per acre	Analysis of determinants Analysis of determinants	Parametric Parametric/econometric
11. Odhiambo (1998)	Micro	Yield/acre		Econometric model
12. Nyoro and Muiruri (1999)	Micro			Parametric/non-parametric

Douglas function with capital K and labour L, Block and Timmer (1994) specify TFP in agriculture as:

$$\lambda_{ag} = \log Y_{ag} - \beta_1 \log K_{ag} - \beta_2 \log L_{ag} \quad \text{.............................(42)}$$

where Y is total output and K and L are capital and labour, respectively. This leaves out land and other inputs such as fertilizer, which are also important in the agricultural production process. Land as a factor of production is left out largely because data on it is too aggregated to allow for its inclusion. Fertilizer is also excluded from the model ostensibly because of its low level of use and the poor quality of data in the country. Inclusion of these variables, according to Block and Timmer (1994), leads to implausible estimates that are negative and insignificant.

Using the residual approach outlined above, Block and Timmer (1994) estimate the annual TFP growth rate at 0.6%[2] for the period 1972-92. This implies that during the period under consideration, agricultural output increased by nearly 0.6% per year beyond the amount accounted for by the increase in capital and labour. It would, however, be interesting to see what happened in the period between 1992 and 2001 when the sector witnessed clear trends of decline. This is however outside the scope of this paper. What perhaps needs to be noted is that while the approach churns out a figure for TFP growth, it does not, besides leaving out important production factors, address itself to issues of efficiency. In addition, other important determinants of productivity such as environmental concerns are left out. The study does not also make a distinction of the varied agro-ecological zones in the country.

[2] This involved the estimation of a production function with a time trend variable to capture the annual rate of agricultural TFP growth.

Another study that uses macro data to analyse productivity in Kenya is that by Njue and Fox (1993). Using macro data from the Ministry of Agriculture and Rural Development, supplemented with some datasets from FAO, the study estimates the multi-product factor productivity index for Kenyan agriculture for the period 1964-89. The overall finding is that productivity in Kenya had declined over the period under consideration. The study does not however explicitly address itself to the causes of the decline. As such, the findings of the study do not readily lend themselves to policy formulation.

3.1.2 Messo studies

There are very few studies on productivity in Kenya that are "messo" in their scope. These studies, as earlier indicated, use mainly national data disaggregated by type of farm, agro-climatic zones, or administrative regions. A good example of such a study is that by Nyoro and Jayne (1999). As indicated in Table 2, the study focuses mainly on the analysis of productivity over time and space. Five of Kenya's eight provinces (Central, Eastern, Rift Valley, Western and Nyanza) were analysed for the period from 1970-1995. The study used secondary data from the Ministry of Agriculture (MoA), the Central Bureau of Statistics (CBS) and from various secondary sources including farm management reports, Development Plans and District Annual Reports. Data on specific crops like coffee, tea, pyrethrum, sugar and rice were also collected from the respective regulatory and marketing bodies, in this case the Coffee Board of Kenya, the Tea Board of Kenya, the Pyrethrum Board, Kenya Sugar Authority and the National Irrigation Board (NIB), respectively.

To measure productivity, the study utilised the partial factor productivity (PFP) concept for both land and labour. The PFP indicators are calculated as the ratio of output to inputs (Q/X_i), where Q is the value of output and X_i is the physical factor input. The value of agricultural production is defined as the product of the output and the average producer price for each year. To arrive at the total value for the whole sector, the total value of each crop was summed across all crops. Following from Block (1994) labour productivity is defined as the inflation-adjusted value of crop output per rural person.

Based on the partial productivity measure, the study shows that labour productivity declined in Kenya from roughly Kshs. 3,000 per rural person between 1970-74 to Kshs. 2,400 per rural person in 1990-94. The study also shows that land productivity had increased greatly in the country until around 1990 after which it started declining. The decline in both labour and land productivity is attributed to the decline in use of fertilizers and hybrid seeds and the contraction of credit schemes in the agricultural sector. The decline is also attributed to the stop-go policy environment in the country, poor sequencing of liberalization policies, poor management of crop cooperatives (particularly coffee), and increased population pressure that has pushed production into marginal areas.

Nyoro and Jayne (1999) also demonstrated wide regional disparities in productivity. According to their results, Central Province has the largest labour productivity in the country at a rate of Kshs. 6,341 compared to Kshs. 1,585 in Eastern Province, Kshs. 1,000 in Rift Valley and Kshs. 2,000 in Nyanza. The findings also indicate that labour productivity had declined steadily, especially in the 1990-1995 period. The decline in labour productivity in most of the regions is attributed to the high growth in rural population. Likewise, land productivity also shows wide regional disparities. Again, land productivity is highest in Central Province than in the other provinces in the country. Unlike labour productivity, land productivity in the regions has shown some remarkable increase especially in the 70s and 80s. The high productivity in Central Province is attributed to the high adoption of fertilizers and high yielding maize varieties and the shift towards high value horticultural crops. Second in the line is the Rift Valley Province where land productivity also initially increased before declining in the 1990s.

On account of the identified constraints to both land and labour productivity, Jayne and Nyoro (1999) outline measures that the Government could undertake to improve productivity in the country. These include improvement of infrastructure (including roads, rail, port and communication), investment in market-oriented agricultural research, investments in private marketing, increasing training in business skills for farmers, and increasing local policy analytical capacity. Although the recommendations of the study are not directly drawn from the data presented in the study, they nevertheless, tally closely with recommendations of the Government (Republic of Kenya, 2001).

An obvious weakness of the study by Nyoro and Jayne (1999), which the authors also acknowledge, is the use of the partial factor productivity measure. As was already indicated, PFP indices do not account for all the inputs used in the production process but instead focus on a single input–land or labour. Therefore, important productivity-enhancing inputs such as technology, infrastructure, extension, input supplies and market outlets are left out in the analysis. A measure that would capture most of the important variables is the total factor productivity, TFP. This measure however requires a more extensive data set, which is seldom available in most developing countries. The challenge is therefore to assemble data to be able to incorporate other important factors of production.

Another weakness of the study, again arising from the measure of productivity that it utilises, is that it ignores issues of efficiency and the environment. Studies elsewhere have shown that these are important determinants of agricultural productivity. As was demonstrated in earlier sections, it is now possible to integrate these variables in measures of agricultural productivity. This issue will be revisited in some detail in section four.

3.1.3 Micro studies

Most of the studies that have been carried out on productivity in Kenya are "micro" in nature. These studies use primary data from statistical surveys at household level to estimate measures of productivity. There are, however, other studies which use non-statistical methods such as rapid rural appraisals and focus group discussions. Since these non-statistical approaches do not provide the input/output data necessary for quantifying productivity trends that is the focus here, they have been left out in this review. The rest of this section is devoted to review of the approaches and findings of the micro studies in Kenya.

As was shown in Table 2, the primary focus of the micro studies has been the analysis of determinants of agricultural productivity in Kenya. Among the productivity studies that are micro in scope are those by Nyariki and Thirtle (2000), Strasberg *et al* (1999), Owuor (1999), Ekborm (1998), Evenson and Mwabu (1998), Place and Hazell (1993) and Nyoro and Muiruri (1999). These studies are empirical in approach and use data largely from surveys. The only exception is the study by Nyoro and Muiruri (1999) that combines participatory rural appraisal methods and household surveys. As was evident in Table 2, the studies differ mainly by their definition of productivity. While some of these studies use the partial factor productivity measure (the value of output over inputs) others utilise other measures of productivity including generic definitions of productivity based on crop yield per acre.

A common feature of most of the micro studies on agricultural productivity is the use of the partial factor productivity measure or variants of it to estimate agricultural productivity. Owuor (1999) for example, used the partial factor productivity measure, defined simply as the ratio of physical output to factor inputs, to analyse productivity among some 1,540 households derived from a rural household survey by the Tegemeo Institute in 1997. The data was clustered into different agro-ecological zones spread in eight provinces and 24 districts in Kenya. The study used two indices of partial productivity, i.e. land and family labour. The two indices were hypothesized to depend on the degree of commercialization and crop mix and the intensity of use of fertilizer among other variables, which are however not discussed in the paper.

The other important study in this category is that by Ekborm (1998), which uses survey data collected over a period of three years in the Kenya highlands. The data covers 252 households. This particular study used a variant of the PFP to measure productivity. For each farm, agricultural productivity is the crop yield weighted by farm area and crop price. This is hypothesized to be a function of labour inputs, materials, physical capital investment, human capital and physical resource endowments. A Cobb-Douglas production function is estimated using a linear estimation technique, the ordinary least squares method (OLS).

Evenson and Mwabu (1998) also used a similar approach in the analysis of the effect of agricultural extension on farmer productivity. The authors estimated a Cobb-Douglas production function in which productivity, defined as farm yield, is a function of the area cropped, labour resources, fertilizers and sprays per acre, extension and other socio-economic and ecological attributes. The function was estimated using a quintile regression technique controlling for the effects covariates of extension. The Cobb-Douglas production function, though widely used, has its own limitation, such as the the assumption of unity between input substitution elasticities. Even more fundamental is the use of a single equation model which ignores the simultaneity inherent in such relationships. Since regressors are endogenous in a single equation model, they will be correlated with the error term, and least squares estimates of parameters will be inconsistent (Greene, 1993).

A familiar solution to this problem is to specify and estimate a system of equations as opposed to a single equation. In a study to analyse the impact of market access on agricultural productivity, Odhiambo (1998) specified and estimated a system of equations in which productivity, defined simply as the value of output per unit of land, was a function of resources used (land, labour), input material (fertilizer, pesticides, herbicides, high yielding variety seeds), credit and market access (defined in terms of time taken to the market). The input use variables were in turn specified as endogenous variables in recognition of their simultaneity with productivity. A three stage least square (3SLS) estimation technique using farm level data collected from 226 households in Meru and Machakos districts was then applied.

Another important study in this category is that by Strasberg *et al* (1999). The overall objective of this study was to analyse the effects of smallholder commercialization on food crop input use and productivity in rural Kenya. A specific objective of the study was to examine the determinants of food crop productivity with a focus on the effects of commercialization. The analysis was based on a national rural household single visit survey of 1,540 rural households. Two econometric models were used to determine the effect of commercialization at both the district and household levels on food crop fertilizer use and productivity. Productivity in the study is defined as the gross value food output per acre. This is hypothesized to depend on inputs used, agro-ecological factors, market infrastructure, socio-demographic characteristics, household assets, a household commercialization index (defined as the percent of the gross value of household crop production), and the regional crop specific intensity indices. An instrumental variable approach was used to estimate the productivity model.

As part of wider study on land tenure and security in Africa, Migot-Adhola, Place and Oluoch-Kosura (1993) examined the effect of land tenure on agricultural productivity in Kenya. The methodology in the study involved a survey of households in Nyeri and Kakamega districts of Kenya. The survey, which was carried out between the period 1985-1986, covered 109 households with both titled and untitled land. In examining the relationship between land tenure and agricultural productivity, the authors employ regression analysis in which production yields from the crops was explained by a host of independent variables, including land rights variables.

Unlike the other micro studies that have used household surveys, the study by Nyoro and Muiruri (1999) combines a survey and participatory rural appraisal in the analysis of the determinants of productivity. Four research sites were selected to represent the different agro-ecological zones in the country. This formed the basis for the survey. The survey was complimented with a national study that involved interviews with personnel from different organizations and businesses involved in agriculture in Kenya. Although the study discusses various determinants of agricultural productivity, it is not clear from the paper how productivity was defined or how its determinants were estimated.

The only study in this category that has used a non-parametric approach to measure productivity growth in Kenyan agriculture is that by Nyariki and Thirtle (2000). The study constructs a Malmquist productivity index of the form discussed in section 2.5 of this paper. The study used primary data collected from Makueni District, which is a low potential agricultural zone in Kenya. The use of a Malmquist has the obvious advantage in that it incorporates efficiency. In fact, this is the only study so far that has incorporated efficiency in the analysis of productivity. As already indicated, the weakness in this approach is that it does not readily lend itself to policy formulation. In other words, the approach does not identify crucial determinants of agricultural productivity. Ideally one would generate the index and use it as a regressand in an econometric model to uncover the determinants of productivity changes.

3.2 Empirical Determinants of Productivity

The studies reviewed in this paper suggest many important hypotheses relating agricultural productivity to its determinants. Although the focus of this review is on the measurement and analysis of agricultural productivity, this section discusses some important results and conclusions from some of the studies. The discussion is organized according to the key explanatory factors found to affect agricultural productivity.

3.2.1 Resource inputs

Resource inputs particularly capital and labour are the first factors on which empirical analysis of productivity have always focused. This is based on the production function analysis which stipulates capital and labour as primary factors of production. Ekborm (1998), using survey data, finds a positive and significant correlation between labour input per farm and productivity. Although only statistically significant at the 10% level of significance, the study also finds that household capital, proxied by the value of domestic animals, capital availability, and non-agricultural farm incomes are positively related to agricultural productivity. Increasing labour and capital availability is therefore seen in this context as being important for productivity increases in the country.

An often-mentioned impediment to agricultural productivity in Kenya especially among small-scale farmers is the lack of credit. It might be argued on the basis of the above findings that increased access to credit can positively influence productivity by increasing the farm's capital base. More directly, access to credit enables farmers to purchase farm materials such as fertilizers, improved seeds, and herbicides that are important for enhancing productivity.

3.2.2 Fertilizer use

Fertilizer is one of the land augmenting inputs that is likely to enhance land productivity. It is widely acknowledged in Kenya and indeed elsewhere that the use of fertilizers leads to higher yields. Studies by Strasberg *et al* (1999), Odhiambo (1998), Owuor (1999), Evenson and Mwabu (1998), Ekborm (1998) have all demonstrated positive and significant statistical relationships between fertilizer use and productivity. Besides, there are numerous farm-demonstrations mainly by physical scientists that have shown the impact of fertilizer use on farm yields. The policy implication of these results is clear: increase fertilizer use to enhance productivity.

Studies in Kenya have however shown that the use of fertilizer is still very low especially among smallholder farmers. According to a study by Argwings-Kodhek (1997), smallholder fertilizer use in Kenya has been stagnant during the 1990s in many places while it actually declined in others. There are many reasons for this[3]. Among them is the high cost of fertilizer after liberalization. Although it was anticipated that the liberalization of fertilizer prices together with other inputs in agriculture would increase their uptake by improving access,

[3] See Mose (1998) for a discussion of factors constraining the use of fertilizers by smallholder farmers in Kenya.

liberalization has actually led to non-use or low use of purchased inputs. This is because prices of the inputs have gone beyond the reach of most farmers. This must have had a negative impact on productivity in the sector.

3.2.3 Market access and orientation

Increased commercialization of agriculture has been an integral part of increasing incomes and improving living standards of rural areas of many developing countries (Strasberg *et al* 1999). Commercialization, it is argued, can positively influence productivity through specialization (better resource allocation) and intensification (increased use of inputs). In developing countries where infrastructure is usually poor, physical access to markets is crucial as this has a direct bearing on farmers' production costs and the prices they receive.

There have been attempts to measure the effects of these factors on productivity in Kenya. Jayne *et al* (1994) found that there is a positive correlation between household agricultural commercialization and productivity. This confirms earlier studies by Owour (1999) and Odhiambo (1998) that demonstrated a positive relationship between the two variables. Owour (1999) found a positive correlation in the degree of commercialization and crop value per unit of land. Land productivity is higher where the degree of commercialization is high. While demonstrating the positive association between market orientation and agricultural productivity, the study by Odhiambo (1998) also brought out the importance of physical access to markets. Generally, farmers who are in close proximity to markets tend to be more productive than those far away from markets. The empirical results from these studies indicate great potential in Kenya for increasing agricultural productivity through better access and orientation to markets.

3.2.4 Extension services

A number of empirical studies in Kenya have considered extension services as an important determinant of agricultural productivity. A case in point is the study by Evenson and Mwabu (1998), which sought to analyse the impact of extension on agricultural productivity. The main finding of the study was that extension services have a discernible impact on productivity. The impact, according to the study, was at the highest top end of the distribution of yields residuals, "suggesting that productivity gains from agricultural extension may be enhancing unobserved productive attributes of farmers such as managerial abilities" (Evenson and Mwabu, 1998: 28). The implication of this finding is that other factors such as farm management abilities and experience affect the effectiveness of extension as a determinant of agricultural productivity. Other studies that have demonstrated the importance of extension for enhancing productivity are those by Odhiambo, (1998) Ekborm (1998) and Nyoro and Muiruri (1999).

Although the importance of extension services in enhancing agricultural productivity are widely acknowledged, the extension system in Kenya has virtually collapsed. The Government adopted the T&V system of extension in 1982 as a supplement to the old system which had been implemented before independence. A salient feature of this system was a regular pattern of visits to farmers by frontline extension workers. Transport and related expenses were therefore an important component of the total budget of the system. The T&V system absorbed most of the budget leaving extension workers with poor remuneration and conditions of service. This was made worse by implementation of SAPs that saw the Government reduce its role in agriculture and particularly extension. Therefore, while evidence shows that extension service is necessary to raise productivity, it has not been an important driver of productivity due to the many problems faced in providing this service.

3.2.5 Farm size

Farm size is one of the factors that has been hypothesized as a determinant of agricultural productivity. Ekborm (1998) and Odhiambo (1998) explicitly include farm size as one of the factors determining agricultural productivity. Ekborm (1998) finds a negative but statistically significant relationship between farm size and agricultural productivity. This implies that smaller farms are more productive than larger farms. According to the author, this finding is plausible because smaller farms are often forced to intensify production to sustain household welfare. Larger farms on the other hand can afford the "luxury" of extensification. The study by Odhiambo (1998) further indicates that the negative relationship between productivity and farm size operates largely through labour resource inputs where smaller farmers tend to use more labour per unit of land than the larger ones.

Several other studies have also reported farm size to be related to technology adoption which in turn increases productivity. For instance, Barker and Herdt (1978) demonstrated that large farmers had higher rate for hybrid usage and were therefore more productive than the smaller ones. In some cases, smallholders lag behind in adoption but later catch up as has been the case with hybrid maize in Kenya (Hassan and Karanja, 1997). Some studies have, however shown productivity not to vary with farm size. Karanja *et al* (1999) show scale to have no effect on hybrid and fertilizer as well as productivity. These results show that the effect of land size on productivity remains largely an empirical question.

3.2.6 Biophysical factors

A number of biophysical factors are hypothesized to influence productivity. These include agro-ecological conditions such as rainfall, soil type, altitude, etc. The empirical studies by Ekborm (1998), Njue and Fox (1993) and Strasberg *et al* (1999) included a number of biophysical variables as determinants of productivity. The results show that although productivity is correlated to some of these variables, for example weather and soil type, the relationships are seldom significant. The only exception in this regard is the finding by Ekborm (1998) of a positive and significant relationship between soil conservation and agricultural productivity. This finding is important given that conservation improves the long-run fertility of soils. In the 1980s and early 1990s, there was a very strong drive for soil conservation in Kenya. Available evidence by English *et al* (1994) shows that the exercise has had some positive impact especially in Machakos where it was concentrated.

3.2.7 Land tenure

There is widespread belief among development economists that tenure security has a bearing on agricultural productivity in developing countries. Tenure security, it is argued, increases credit use through greater incentives for investment in agriculture and reduced incidences of land disputes (Feder and Noronha, 1987, Barrows and Roth, 1990). The type of land tenure also influences investments in fixed inputs such as machinery, which are important for enhancing productivity. A number of studies in Africa have formally tested the nature and strength between tenure security and agricultural performance (e.g. Hayes, Roth and Zapeda (1993) in the Gambia; Place and Hazell, (1993) in Ghana, Kenya and Ruanda; and Migot-Adhola, Place and Oluoch-Kosura, (1993) in Kenya.

In Kenya, Migot-Adhola, Place and Oluoch-Kosura, (1993) found no significant relationship between crop yield and land rights. The study finds further that the presence of land title did not affect yields in any significant way. These results are indeed surprising as they go contrary to the widely held notion that security of tenure and titling leads to higher yields. It is notable that the study focused largely on smallholders with an average land parcel of between 0.53 ha to 4.1 ha. It would be interesting to see whether these results are replicated for larger farmers and in other regions in Kenya.

4. Evaluation of Previous Work and New Directions in Empirical Research

The foregoing section has reviewed the approaches and findings of representative empirical studies on agricultural productivity in Kenya. This section discusses the validity of the empirical methodologies, focusing largely on the theoretical basis of estimations done, the types and sources of data used, and the statistical assumptions made. More importantly, the discussion focuses on the comprehensiveness of the approaches used in estimating and explaining productivity in Kenya and their relevance in policy formulation. The section also draws implications for new direction on productivity measurement and analysis in Kenya.

4.1 Average versus Marginal Productivity Indicators

The studies on agricultural productivity in Kenya reviewed so far can be classified into two main categories depending on the productivity indicators generated. On the one hand are studies that generate the average productivity indicators. This is usually a simple ratio of output divided by inputs. This can either be partial or total (hence partial and total factor productivity). Good examples of studies that fall in this category are those by Njue and Fox (1993) and Nyariki and Thirtle (2000), in which simple ratios or indices are derived for agricultural productivity. On the other hand are studies (and these are the majority) that generate marginal effects. Examples are those by Strasberg *et al* (1999), Odhiambo (1998) and Evenson and Mwabu (1998).

As pointed out by Kelly *et al* (1995), average productivity indicators provide little information on how to improve productivity. Policy makers are more interested in knowing how to increase productivity. This requires knowledge of the marginal effects. A marginal product shows how much more gross output (or value) a producer is likely to get by increasing a particular input by a unit. Even more fundamental is the fact that it is possible with marginal values to predict how farmers are likely to respond to various policies. In terms of relevance to policy making, approaches that generate marginal productivity indicators are preferable. It can be noted here, however, that both approaches can be utilised jointly where indices generated as proxies for productivity are used as regressands to yield marginal effects.

4.2 Use of Alternative Models

A major weakness of the studies on productivity in Kenya is their inability to rigorously bring out the sources or determinants of agricultural growth and productivity. This is because most of these studies have not been rigorous enough, as one would have expected, given the kind of methodologies reviewed in section 2 of this paper. To better understand the nature and determinants of agricultural productivity in the country, there is need to employ methodologies that are more appropriate in terms of scope and results. Techniques such as data enveloping analysis (DEA) and stochastic frontier models have clear advantages in the analysis of productivity over many of the techniques that have so far been used. While DEA may be particularly useful for analysis at the macro level, stochastic frontier models are easier to apply on farm level data. It is also possible to borrow and effectively utilise methodologies such as the growth accounting framework used in macroeconomics to decompose growth and productivity in the agricultural sector.

4.3 Model Specification

Some studies on agricultural productivity in Kenya have involved the estimation of production functions, either as a single equation or as a system of equations. Under the former, the approach has been to estimate a functional form of a production function, typically the Cobb-Douglas type. The rationale for using the Cobb-Douglas production function with all its limiting assumptions has been that it is "relatively simple and convenient to specify and interpret" (Ekborm, 1998:6). However, this simplicity and convenience needs to be weighed against its assumptions such as unity between input substitution elasticities. Even more serious is the specification and estimation of a single equation that invariably ignores the simultaneity inherent in most relationships. This brings in the possibility of simultaneous equation bias. In those studies that have attempted to incorporate simultaneity in variables, problems such as the degree of freedom, and multicollinearity between independent variables are common. This in most cases invalidates the conclusions from the analysis. The choice of models in the analysis of agricultural productivity is therefore very important and needs careful consideration.

4.4 Issues of Resource use Efficiency

The question of efficiency in resource allocation by farmers is an important one yet only one of the twelve studies reviewed here have implicitly incorporated issues of efficiency. This indeed is a major drawback to the understanding of the performance of agriculture in the country and is a major weakness of the existing studies. From a theoretical perspective, productivity (the ratio of output to inputs) varies due to differences in production technology, differences in the efficiency of the production process, and differences in the environment with which production takes place (Lovell, 1993). Therefore, efficiency change should be part and parcel of any model that attempts to explain changes in agricultural productivity.

As noted in section 2.3, there have been attempts in the literature to include efficiency change as a component of productivity change. This however depends on the data one has to work with and the assumption one is willing to make. According to Lovell (1993), the data required for this purpose can be a single time series or a panel and can consist of quantities only or quantities and prices. Assumptions can be strong or weak. Strong assumptions such as constant returns to scale and technology would allow the use of a single time series on quantity data. This would enable one to make conclusions on the contribution of efficiency to productivity change. The challenge therefore is to obtain adequate and reliable data for the analysis of productive efficiency in Kenyan agriculture.

4.5 Environmental Impact

Conventional measures of productivity used in Kenya and indeed in the broad literature on agricultural productivity are based on marketed outputs and purchased inputs. However, in the agricultural sectors, purchased inputs used to produce marketed outputs are also associated with non-marketed by-products such as environmental impact. In the context of a developing country like Kenya, leaving out environmental impact in the measurement of productivity overestimates productivity by failing to incorporate the negative effects of production. This raises issues of whether it is possible to incorporate environmental impact into the measurement of productivity. Recent works by Oskam (1991), Ball *et al* (1997), Ball *et al* (2000) and Hailu and Veenam (2001) have answered this question in the affirmative; so long as the environmental impact is quantifiable, it can be incorporated into a Malmquist productivity index which requires only quantity information in its construction. There are also attempts in the literature to use parametric approaches to incorporate environmental impacts on productivity measures (for example Hailu and Veenam, 2001).

The incorporation of environmental impact in productivity analysis requires the availability of quantifiable information on some of the key environmental variables. To our knowledge, this kind of data is largely missing. Although there are methodologies such as the data enveloping analysis (DEA) which can be used, the lack of data may hinder the incorporation of environmental impact in productivity analysis. For developing countries like Kenya, the challenge is really one of availing data for this kind of analysis.

4.6 Effects of Transaction Costs

There have been attempts in Kenya to explain differentials in productivity between regions and even between groups of farmers (for example, Nyoro and Jayne, 1999). The underlying assumption in most of these studies is that farmers in one region or of a particular size face the same set of sale and purchases prices. In practice, however, farmers even from the same region face different transaction costs. Transaction costs typically involve the costs of information, search, negotiations, screening, monitoring, coordination and enforcement (Hoff and Stiglitz, 1993). In agriculture, transportation costs are an important component of the transaction costs. It is notable that these transaction costs tend to be high in developing countries because of market failure and poor infrastructure. Also important here is the means of transport and whether or not the producers own the means of transport or hire them in the market.

The consequence of transaction costs is that each farmer will face a unique set of effective prices. Optimal resource allocation will consequently differ for each farm according to the farms' effective prices determined by its transaction costs. The implication of this in terms of productivity analysis is that transaction costs need to be incorporated in explaining productivity differentials. The studies we have reviewed in the last section have unfortunately not addressed this important issue. Therefore, it would appear that there is need to generate highly disaggregated data to be able to capture the impact of transaction costs. This calls for micro analysis of agricultural productivity.

4.7 Data Types and Sources

The data used in the analysis of agricultural productivity in Kenya vary widely by source and quality. The studies reviewed in this paper have typically used three types of data: macro, meso and micro. Macro and meso data are mainly obtained from the Ministry of Agriculture. The Central Bureau of Statistics (CBS) and the Department of Resource Surveys and Remote Sensing have also been important sources of data used in productivity analysis. Macro and messo data in Kenya suffers from a number of problems. One, the production and acreage data is not obtained by physical measurement but by estimations done by field extension staff. The data may therefore not be very accurate and could underestimate or overestimate actual crop areas and production. Second, the macro data, which is compiled from districts, is highly inaccurate as is plagued with typographical/arithmetic errors and lack uniformity in the reporting system. Third, the data is highly disaggregated and does not differentiate the policy relevant groups of producers, for example large and small farmers. Part of this deficiency is attributed to the dwindling capacity of CBS in data collection due to serious financial constraints. Conclusions based on this kind of data should therefore be interpreted with caution.

Most studies in Kenya have used micro data collected by individual researchers. In certain cases, for example the study by Evenson and Mwabu (1998) micro data collected by the Central Bureau of Statistics is used. Compared to macro data, micro data sets are the best source of information for analysing productivity at the firm-level and can greatly improve estimates of productivity especially where macro data is missing (Kelly *et al*, 1995). A major weakness of micro data collected by the CBS is that it is collected on the basis of the NASSEP II frame which excludes some districts. As such, this data is not comprehensive. In addition, the methodology used by CBS does not in any way apportion areas in mixed-crop cases.

Micro data collected by individual researchers are good especially if they are by multiple interview surveys. This is because the data can be as detailed as desired and can capture key determinants of productivity. This will however depend on whether farmers have the information. Where single interviews are used, long recalls to obtain household input and production data or information on farmers' knowledge, attitudes and practices are necessary. This is a potential cause of inaccuracy. The loss of inaccuracy in the data collected through single visit surveys should however be weighed against the benefit of rapid analysis and reporting. There is also the issue of costs. Collection and compilation of primary data is usually very costly in terms of time and financial resources. Such costs should clearly be weighed against alternatives.

To bridge data gaps in agricultural productivity analysis in Africa, Kelly *et al* (1995) have proposed a number of measures. Among these is the need to use both micro and macro data in a complimentary manner. The authors recommend cross-fertilization of detailed micro studies and broad macro-data collection and reporting efforts. This we believe, can be an important milestone in agricultural productivity analysis in the country. Readon *et al* (1995) also underscore the need to generate consistent macro-data in unbroken series to analyse macro-productivity trends. Such an initiative is already underway in KIPPRA and should provide a sound basis for the surveillance of the country's agricultural production situation.

5. Conclusions and Implications for Further Research

The objective of this paper was to review studies that have attempted the measurement and analysis of agricultural productivity in Kenya. The review seems to support the following major conclusions. First, that most productivity studies have not been rigorous and have not utilised advanced methodologies used elsewhere. The studies have largely ignored or not incorporated issues of efficiency. Also left out in virtually all the studies are environmental concerns. Future studies can rectify this by incorporating these concerns through the use of appropriate techniques.

Second, to be more relevant to policy formulation, future studies of agricultural productivity should generate more of marginal effects of productivity than average effects. In other words, agricultural productivity studies should focus more on the determinants of agricultural growth and productivity than on trends. Policy makers, donors, and other development practitioners are more interested in knowing how to increase productivity than its trend over time. This calls for more parametric analysis of productivity.

Third, appropriate and reliable data for measuring and analysing agricultural productivity has been lacking. Investing in the generation of reliable data as an initial step in productivity analysis may be necessary. Where secondary data is to be used, it would be necessary to update and validate different data series to ensure that the data is reliable. The better option is for future studies to rely more on primary data in the analysis of agricultural productivity in the country. As data collection and analysis costs are high, researchers and statistical sources need to ensure maximum complimentarity among different types of surveys and data.

Lastly, that some conclusions that go contrary to general expectations (for example in the case of the impact of land tenure) may be due to conceptual and operational definitions in-built in the research process. In other cases, it may be because of differing social, cultural and institutional environments. In both of these cases and other related cases, there is need for further research to clarify or confirm some of the conclusions.

References

Aigner, D., K. Lovell, and P. Schmidt (1977). "Formulation and estimation of stochastic frontier production function models". *Journal of Econometrics*, 6: 21-38.

Argwings-Kodhek, G. (1997). "Factors constraining fertilizer use in Kenya: an interim report. Tegemeo Institute of Agricultural Policy and Development, Nairobi: Egerton University.

Barker, R. and R.W. Herdt (1978). "Equity implication of technology changes". In *Interpretative analysis of selected papers from changes in rice farming in selected areas of Asia*. Los Banos: International Development Rice Research Institute.

Ball, V.E, J-C. Bureau, Nehring, R. and A. Somwaru (1997). "Agricultural productivity revisited". *American Journal of Agricultural Economics,* 79:4: 1045-63.

Ball, V.E., C.A.K Lovell, H. Luu and R. Nehring (2000). *Incorporating environmental impacts in the measurement of agricultural productivity* School of Economics, University of South Wales, Sydney.

Barrows, R. and M. Roth (1990). "Land tenure and investment in African agriculture: theory and evidence". Madison: LTC University of Wisconsin.

Battese, G.E and G.S. Corra (1977). "Estimation of frontier production functions: with applications to the pastoral zone of Eastern Australia". A*ustralian Journal of Agricultural Economics*, 21(3)169-179.

Battese, G.E and S. S. Broca (1996). Functional forms of stochastic frontier production functions and models for technical efficiency effects: a comparative study for wheat farmers in Pakistan. CEPA Working Papers No. 4/96, University of New England, Australia.

Battese, G.E and T.J. Coelli (1998). Productivity of Mongolian grain farming: 1976-89. CEPA Working Papers No. 2/96, University of New England, Australia.

Bauer, P.W. (1990). "Decomposing TFP growth in the presence of cost inefficiency, non-constant returns to scale and technological progress'. *Journal of Productivity Analysis,* 1(4) (June): 287-300.

Biswanger, H.P. (1974). "A cost function approach to the measurement of elasticities of factor demand and elasticities of substitution". *American Journal of Agricultural Economics*, 56(2):377-386.

Block, S. (1992). Agricultural productivity and its contribution to agricultural growth in Kenya. Consultant report submitted to USAID/Kenya, Nairobi.

Block, S. and C.P. Timmer (1994). Agriculture and economic growth: conceptual issues and the Kenyan experience. Consultant report submitted to USAID/Kenya, Nairobi.

Block, S. (1994). A new view of agricultural productivity in sub-Saharan Africa. *American Journal of Agricultural Economics,* 76:619-624.

Dawson, P. J. and J.L. Lingard (1991). Measuring technical efficiency on Phillipine farms. Department of Economics, University of Nottingham.

Denison E.F. (1972). "Classification of sources of growth". *Review of Income and wealth,* 18:1-25.

English, J., Tiffer M., and M. Mortimore (1994). Land resource management in Machakos District, Kenya: 1930-1990. World Bank Environment Paper No. 5.

Ekborm (1998). Some determinants to agricultural productivity-an application to Kenyan highlands. Paper presented at the World Conference of Environmental Economics, Venice Italy, 25-27 June 1998.

Evenson, R.E. and G. Mwabu (1998). "The effects of agricultural extension on farm yields in Kenya". Center Discussion Paper No. 708, Economic Growth Center, Yale University.

Fare, R and C.A.K. Lovell (1978). "Measuring the technical efficiency of production". *Journal of Economic Theory,* 19(1) (October): 150-162.

Fare, R., S. Grosskopf, B. Lingren and P. Ross (1989). "Productivity developments in Swedish hospitals: a Malmquist output index approach. Working Paper, Department of Economics, Southern Illinois.

Feder, G. and R. Noraaha (1989). Land rights systems and agricultural development in sub-Saharan Africa. World Bank Research Observer 2(2), 143-169.

Greene, W.H. (1990). "Maximum likelihood estimation of econometric frontiers functions". *Journal of Econometrics,* 13(1) (May): 27-56.

Grosskopf, S. (1993). Efficiency and productivity. In Fried, H.O, Lovell, C.A K. and Schmidt, S.S.(eds). *The measurement of productive efficiency: techniques and applications*". London: Oxford University Press.

Griliches, Z (1967). 'The sources of measured Productivity growth: United States agriculture, 1940-1960" *Journal of Political Economy* 71: 331-346.

Hailu, A. and T.S.Veenam (2001). "Alternative methods for environmentally adjusted productivity analysis". *Agricultural Economics,* 25:211-218: Elsevier.

Hassan, R.M. and D.D. Karanja (1997). Increasing maize production in Kenya: technology, institutions and policy. In Byelee, D. and C.K. Eicher (eds). *Africa emerging maize revolution*. Boulders, Lynne Rienner Publishers.

Hayami, Y. and V.Ruttan (1985). *Agricultural development: an international perspectiuve*. Baltimore: John Hopkins University Press, 1985.

Hayes, J., M. Roth and L. Zapenda (1993). "Tenure security, investment and productivity in Gambian agriculture: a generalized probit analysis. *American Journal of Agricultural Economics,* 79: 369-82.

Herdt, R.W. and M.A Mandac (1981). "Modern technology and economic efficiency of Philippines rice farmers". *Economic Development and Cultural Change*, 29: 375-98.

Holf K.B.A., and J.E. Stiglitz (1993). *The economics of rural organization: theory, practice and policy*. Oxford: Oxford University Press.

Jayne, T.S., Khatri, Thirtle, C. and Readon (1994). Determinants of productivity change using a profit function approach: smallholder agriculture in Zimbabwe. *American Journal of Agricultural Economics,* 76(3): 613-618.

Jorgenson, D.W.and Z. Griliches (1967). "The explanation of productivity change". *Review of Economics Studies*, 34(3) (July): 249-282.

Karanja, D., T.S. Jayne and P. Strasberg (1999). Determinant of input use and maize productivity in Kenya: implication of cereals marker reforms Kenya. Agricultural marketing and policy analysis project, Tegemeo Institute/Michigan State.

Kelly, V., J. Hopkins, T. Reardon and E. Crawford (1995). "Improving the measurement and analysis of African agricultural productivity: promoting complementarities between micro and macro data". MSU International Development Paper No 16: Michigan State University.

Kendrick, J.W. (1961). "*Productivity trends in the United States*". Pricenton: National Bureau of Economic Reserach.

Lau, L. and P. Yotopolous (1971). "A test of relative efficiency and application to Indian agriculture". *American Economic Review,* 61 (March):94-109.

Lovell, K.C.A. (1993). "Production frontiers and productive efficiency". In Fried, H.O Lovell, K.C.A and Schmidt, S.S.(eds.) *The measurement of productive efficiency: techniques and applications*". London: Oxford University Press.

Lundvall, K. and G.E. Battese (1998). Firm size, age and efficiency: evidence from Kenyan manufacturing firms. CEPA Working Papers No. 7/98, University of New England, Australia.

Malmquist, S. (1953). 'Index numbers and indifference surfaces". *Trabajos de Estadistica,* 4: 209-42.

Meeusen W. and J.van den Broeck (1977). "Efficiency estimation from Cobb-Douglas production functions with composed error". *International Economic Review*, 18(2):435-444.

Migot-Adhola, S.H., F. Place and W. Oluoch-Kosura (1993). Security of tenure and land productivity in Kenya. In Bruce, J. and Migot-Adhola, S.H (eds). *Searching for land tenure security in Africa*. Kendall/ Iowa: Hunt Publishing Company.

Njue, E. and G. Fox (1993). Productivity in Kenyan agriculture: 1964-1989. Working Paper WP 93/02, Department of Agricultural Economics and Business, University of Guelph, Ontario.

Nyoro, J.K. and T.S. Jayne (1999). Trends in regional agricultural productivity in Kenya. Kenya agricultural marketing and policy analysis project. Tegemeo Institute/Michigan State University.

Nyariki D.M. and C. Thirtle (2000). "Technical innovations and farm productivity growth in dryland Africa: the effects of structural adjustment on smallholders in Kenya". *Agrekon*, Vol 39, No.4: 597-606

Nyoro, J.K. and H.K. Muiruri (1999). *Policies for agricultural sustainability in Kenya.* London: IIED.

Odhiambo, W. (1998). *Productivity, market orientation and agricultural intensification: a comparative analysis of smallholder farmers in Meru and Machakos Districts of Kenya*. Verlag Ulrich E.Grauer Stuttgart.

Oskam, A.(1991). "Productivity measurement: incorporating environmental effects of agricultural production". In K. Burger *et al* (eds). *Agricultural economics and policy: international challenges for the nineties*. Amsterdam: Elsevier.

Owuor, J. (1999). Determinants of agricultural productivity in Kenya. Kenya agricultural marketing and policy analysis project. Tegemeo Institute/Michigan State University.

Place, F., M. Roth and P. Hazell (1993). "Land tenure security and agricultural performance in Africa: overview of research methodology". In Bruce, J. and Migot-Adhola, S.H (eds). *Searching for land tenure security in Africa*. Iowa: Kendall/Hunt Publishing Company.

Republic of Kenya (2001). Poverty Reduction Strategy Paper. Nairobi: Ministry of Finance and Planning.

Readon T., V. Kelly, E. Crawford, T.S. Jayne, K. Savadogo and D. Clay (1996). *Determinants of farm productivity in Africa: a syntheses of four case studies*. Department of Agricultural Economics, Michigan States University (MSU).

Sadoulet, E and A. Janvry (1995). *Quantitative development policy analysis*. London: The John Hopkins University Press.

Schmidt, P and R.C. Sickles (1984). "Production frontiers and panel data. *Journal of Business and Economics Statistics,* 2: 367-374.

Savadogo, K. Readon, T. and Pitola, K. (1994). Determinants of farm productivity and supply response in Burkina Faso. Department of Agricultural Economics, Staff Paper No. 94-79. East Lansing: Michigan State University.

Solow R. M. (1957). "Technical change and the aggregate production function". *Review of Economics and Statistics,* 39(3) (August): 312-320.

Strasberg, P.J., T.S. Jayne, T. Yamano, J. Nyoro, D. Karanja and J. Straus (1999). Effects of commercialization on food crop input use and productivity in Kenya. Working Paper No.71, Michigan State University: Department of Agricultural Economics.

Thirtle, C. J. Atkins, P. Bottomley, N. Gonese, N. Govereh and Y. Khatri (1993). Agricultural productivity in Zimbabwe, 1970-89. *Economics Journal*, 103 (March): 474-480.

Varian, R.H. (1992). Microeconomic analysis (3rd edition). New York: W.W Norton and Company.

Yotopoulos, P. and L. Lau (1973). "A test for relative economic efficiency: some further results". *American Economic Review,* 63: 214-23.

KIPPRA PUBLICATIONS

Conference Proceedings

Report of the proceedings of the AERC-KIPPRA World Trade Organization (WTO) Workshop, 2000.

Report of the proceedings of the International Conference on Finance and Development: Evidence and Policy Issues, 2001.

Discussion Papers

The exchange rate and the interest rate differential in Kenya: a monetary and fiscal policy dilemma. Njuguna S. Ndung'u, DP No. 1, 2000: ISBN 9966 949 00 3.

Macro models of the Kenyan economy: a review. Stephen N. Karingi and Njuguna S. Ndung'u. DP No. 2, 2000: ISBN 9966 949 01 1.

A review of Kenya's current industrialization policy. Eric E. Ronge and Hezron O. Nyangito. DP No. 3, 2000: ISBN 9966 949 02 X.

Delivery of services to smallholder coffee farmers and impacts on production under liberalization in Kenya. Hezron O. Nyangito. DP No. 4, 2001: ISBN 9966 949 03 8.

Banking sector interest rate spread in Kenya. Njuguna S. Ndungu and Rose W. Ngugi. DP No. 5, 2000: ISBN 9966 949 04 6.

Beer taxation in Kenya: an assessment. Stephen N. Karingi, Mwangi S. Kimenyi, Njuguna S. Ndung'u. DP No. 6, 2001: ISBN 9966 949 09 7.

Vision and long term development strategy for Kenya's tourism industry. Moses M. Ikiara. DP No. 7, 2001: ISBN 9966 949 15 1.

Specifying and estimating partial equilibrium models for use in macro models: a road map for the KIPPRA-Treasury Macro Model. Alemayehu Geda and Njuguna S. Ndung'u. DP No. 8, 2001: ISBN 9966 949 16 X.

Determinants of poverty in Kenya: household-level analysis. Alemayehu Geda, Niek de Jong, Germano Mwabu and Mwangi S. Kimenyi. DP No. 9, 2001: ISBN 9966 949 17 8.

Kenya's exchange rate movement in a liberalized environment: an empirical analysis. Maureen Were, Alemayehu Geda, Stephen N. Karingi and Njuguna S. Ndungu. DP No. 10, 2001: ISBN 9966 949 24 0.

Theoretical base for the Kenya macro model: the KIPPRA-Treasury macro model. Free Huizinga, Alemayehu Geda, Njuguna S. Ndung'u and Stephen N. Karingi. DP No. 11, 2001: ISBN 9966 949 25 9.

Predicting household poverty: a methodological note with a Kenyan example. Germano Mwabu, Mwangi S. Kimenyi, Paul Kimalu, Nancy Nafula and Damiano Kulundu Manda. DP No. 12, 2002:ISBN 9966 949 28 3.

Human capital externalities and returns to education in Kenya. Damiano Kulundu Manda, Germano Mwabu, Mwangi S. Kimenyi. DP No. 13, 2002: ISBN 9966 949 18 6.

The decline in primary school enrolment in Kenya. Arjun Bedi, Paul Kieti Kimalu, Damiano Kulundu Manda, Nancy Nelima Nafula. DP No. 14, 2002: ISBN 9966 949 19 4.

Land laws and land use in Kenya: implications for agricultural development. Walter Odhiambo and Hezron Nyangito. DP No. 15, 2002: ISBN 9966 949 23 2.

Better understanding of the Kenyan economy: simulations from the KIPPRA-Treasury Macro Model. Maureen Were and Stephen Karingi. DP No. 16, 2002: ISBN 9966 949 31 3.

Performance of Kenya's wheat industry and prospects for regional trade in wheat products. Hezron Nyangito, Moses Ikiara and Eric Ronge. DP No. 17, 2002: ISBN 9966 949 35 6.

Impact of institutional and regulatory framework on the food crops subsector in Kenya: 1990-1999. Hezron Nyangito and Lydia Ndirangu. DP No. 18, 2002: ISBN 9966 949 36 4.

Impact of tourism on environment in Kenya: status and policy. Moses Ikiara. DP No. 19, 2002: ISBN 9966 949 37 2.

Review of government policies for the promotion of micro and smallscale enterprises in Kenya. Eric Ronge, Lydia Ndirangu and Hezron Nyangito. DP. No. 20, 2002: ISBN 9966 949 38 0.

Tobacco excise tax in Kenya: an appraisal. Jane Kiringai, Njuguna S. Ndumg'u, and Stephen N. Karingi. DP No. 21, 2002: ISBN 9966 949 33 x

A*nalysis of Kenya's export performance: an empirical evaluation*. Maureen Were, Njuguna S. Ndung'u, Alemayehu Geda, Stepehen N. Karingi. DP No. 22, 2002: ISBN 9966949 40 2.

Prospects of Kenya's clothing exports under AGOA after 2004. Moses M. Ikiara and Lydia Ndirangu. DP No. 24, 2003: ISBN 9966 949 43 7.

Occassional Papers

Strengthening the link between policy research and implementation. Kang'ethe Wamaitha Gitu. OP No. 1, 2001: ISBN 9966 949 07 0.

Effective private sector representation in policy formulation and implementation. Mwangi S. Kimenyi. OP No. 2, 2001: ISBN 9966 949 27 3.

Agriculture, economic growth and poverty reduction. Mwangi S. Kimenyi, OP No. 3, 2002: ISBN 9966 949 32 1.

Post-Doha African challenges in the sanitary and phytosanitary and trade related intellectual property rights agreement. Hezron Nyangito, OP No. 4, 2002: ISBN 9966 949 34 8.

Policy Papers

Policy and legal framework for the tea subsector and the impact of liberalization in Kenya. Hezron O. Nyangito. PP No. 1, 2001: ISBN 9966 949 05 4.

Policy and legal framework for the coffee subsector and the impact of liberalization in Kenya. Hezron O. Nyangito. PP No. 2, 2001: ISBN 9966 949 06 2.

Special Reports

Legal and other constraints on access to financial services in Kenya: survey results. KIPPRA, Private Sector Development Division. SR No. 1, 2001: ISBN 9966 949 08 9.

Thinking about regulating? The better regulation guide. KIPPRA, Private Sector Development Division. SR No. 2, 2002: ISBN 9966 949 20 8.

Policy timeline and time series data for Kenya: an analytical data compendium. KIPPRA, SR No. 3, 2002: ISBN: 9966 949 30 5.

Working Papers

Road infrastructure policies in Kenya: historical trends and current challenges. Wilson S. K. Wasike. WP No. 1, 2001: ISBN 9966 949 11 9.

Policy framework of Kenya's tourism sector since independence and emerging policy concerns. Moses M. Ikiara. WP No. 2, 2001: ISBN 9966 949 12 7.

A review of poverty and antipoverty initiatives in Kenya. Damiano Kulundu Manda, Mwangi S. Kimenyi and Germano Mwabu. WP No. 3, 2001: ISBN 9966 949 13 5.

Education indicators in Kenya. Paul K. Kimalu, Nancy Nafula, Damiano Kulundu Manda, Germano Mwabu and Mwangi S. Kimenyi. WP No. 4, 2001: ISBN 9966 949 14 3.

Estimation procedure and estimated results of the KIPPRA-Treasury macro model. Alemayehu Geda, Stephen N. Karingi, Njuguna S. Ndung'u, Marein van Schaaijk, Maureen Were, Willis Wassala and John Obere. WP No. 5, 2001: ISBN 9966 949 26 7.

A situational analysis of poverty in Kenya. Paul Kimalu, Nancy Nafula, Damiano Kulundu Manda, Germano Mwabu and Mwangi S. Kimenyi. WP No. 6, 2002: ISBN 9966 949 29 1.

Budget reforms and the Medium-Term Expenditure Framework in Kenya. Jane Kiringai and Geoffrey West. WP No. 7, 2002: ISBN 9966 949 21 6.

Developing a revival strategy for Kenya's cotton-textile industry: a value chain approach. Moses Ikiara and Lydia Ndirangu. WP No. 8, 2003: ISBN 9966 949 39 9.