1. Introduction

1.1 Background

Lesotho is a small mountainous country situated in the southern part of Africa. It occupies 30 355 sq. km and has a population of 1 825 000 (1992 estimates) of which 85 percent resides in the rural areas. Due to labour migration the *de facto* population is estimated at 1 460 000, which means that approximately 8 percent of the population is absent from Lesotho.

About 76 percent of Lesotho's area is classed as suitable for agriculture. Only 14 percent of this agricultural land is cropped, the remaining 86 percent is pastureland (BOS 1994a). Both lands need to be carefully managed given the high susceptibility to erosion which is largely due to careless management of agricultural land and the prevalence of overgrazing and cultivation techniques that promoted erosion in the past. The problem of erosion is now so acute that in some locations it prevents the introduction of many field crops and large ruminants (ISNAR 1989). Conservation of the agricultural resource base therefore remains a central problem confronting agricultural research and development in Lesotho.

Inspite of Lesotho's poor agricultural resources and although only a small percentage of total area of the country is arable, agriculture is the primary occupation of 85 percent of Basotho (Lesotho people). It accounts for approximately 10 percent of the country's GNP (1993 estimates) and fetches approximately 23 percent export earnings. Agriculture and animal husbandry constitute Lesotho's major farming. Production of arable land consists of maize, sorghum and beans in summer; and wheat, peas, barley and oats in winter. While much of the yield is used for subsistence, there are exportable surpluses of most crops. The chief source of wealth lies in keeping livestock. Sheep, Angora goats and, to a lesser extend, cattle are of major economic importance, wool and mohair being Lesotho's principal exports.

1.2 Problem Definition

Agriculture is the main contributor to Lesotho's Gross Domestic Product. However, its relative contribution to Lesotho's GDP has declined from 16 percent in 1988 to 10 percent in 1993 (BOS 1994b). Dependence on the wages of mine labour in the Republic of South Africa has in the same period grown from 38 percent to over 50 percent. In terms of the labour available to agriculture, this means that half of Lesotho's able bodied men are working away from their homes at any point in time. This is particularly acute in the rural areas and it is estimated that 70 percent of the agricultural labour is done by women (ISNAR 1989).

Lesotho's agricultural labour supply suffers a typical paradox of high rural unemployment and a limited capacity to absorb the rapid growth of population (2.6 per annum) at the same time that there is a pronounced labour shortage for some farming operations. This is due to the low level of productivity in agriculture which does not match the earning potential of other labour opportunities.

Given the growing pressure on the arable land, the fact that agricultural production has not kept pace with the increase in population, the low rate of return to agriculture, the depressed rural incomes, clearly agriculture has to be made more productive and efficient. Several attempts have and are still being made by the government of Lesotho to make agriculture more productive. Some of these attempts include the establishment of the Agricultural Research Division (ARD) in 1952 by the government to undertake agricultural research to foster agricultural productivity in Lesotho. Also, an agricultural research system has been established recently (1989) with the main objectives of providing new technologies, improving practices that increase productivity of agricultural land and labour, raising farm incomes and conserving the natural resource base for future generations of Basotho.

The government of Lesotho (GOL) has adopted a strategy of intensification of agricultural production in order to address the crisis in agriculture, mainly to enhance self-sufficiency in agricultural products which will help to combat high rural unemployment, depressed rural incomes, and other rural problems. This strategy requires new and improved technologies that the Lesotho agricultural research system must select, screen, and adapt for use by the Basotho agricultural producers. These needs are basically in the form of new technologies that meet the following goals:

- increase farm cash income: by lowering unit costs of production, introducing new high-value crops and varieties that produce higher yields, and cultivation practices that are more economical;

- provide technological inputs and new agronomic practices that can overcome labour constraints: herbicides, mechanisation and machinery, cropping patterns, cycles and timing of farm operations;

- provide technological packages for intensification of production of basic grains and vegetables in the most productive lands; and

- introduce practices, crops, varieties and technology that protect and enhance the productivity of the natural base: improved management of soil, water resources, agroforestry and conservation agriculture (ISNAR 1989).

These objectives are in line with the national development policy for the agricultural sector which was formulated in consideration of the constraints and potential of agriculture in Lesotho. The objectives of the policy are as follows:

- to move towards self-sufficiency in basic foodstuffs;

- to conserve the natural resource base;

- to increase farm incomes and raise the productivity and profitability of agriculture;

- to identify new high-value crops and agricultural products and diversify the base of production and sources of income; and

- to increase employment (5th Five-Year Development Plan 1991/92 - 95/96).

Agricultural research in Lesotho is geared towards fulfilling these objectives.

Agricultural research in Lesotho is basically project-driven both in terms of funding and program orientation. During the 1980s and the early 1990s operational support for programs, the capital funds for buildings and equipment for field research, and the training costs of research staff were provided almost entirely by donors, with USAID being the major source of funds. Other donors were FAO, ISNAR, OECD and SACCAR ('Matli (the director of ARD) 1995, pers. comm.). The GOL's contribution in agricultural research funding has always been minimal comprising mainly personnel emoluments costs.

The Agricultural Research Division (ARD) of Lesotho conducts almost all the country's agricultural research. Nevertheless, there are a few other institutes that engage in a limited amount of agricultural research. These are the Department of Livestock of MACM which conducts some research on small game, dairy, fisheries, poultry, and range management; the Forestry Research Section (FRS) of the Division of Forestry within the Department of Conservation and Forestry of MACM which conducts forestry research; the Institute of Southern African Studies (ISAS) of NUL which conducts some research on the marketing of agricultural products such as grains, livestock, and vegetables; the Lesotho Agricultural College which conducts applied research in cooperation with ARD; and the Faculty of Agriculture (FA/NUL).

While agricultural research is important to Lesotho's agricultural sector, more especially given the above problems facing the agricultural sector, it is also important to know the extent of any impact of the funds invested in agricultural research on agricultural output. Having this kind of information may be useful because it should enable a more informed policy response, especially when the government has often been criticised of underspending on agricultural research. For example, the policy response may take the form of diverting public funds to other activities offering a potentially higher return in the absence of causal relationship between research expenditures and agricultural output, or, of increasing research expenditures in the presence of causal relationship between research expenditures and agricultural output.

1.3 Objectives

The main objective of this study is to analyse the empirical relationship between public sector agricultural research and agricultural output in Lesotho. More specifically, it is

- to investigate if there is a causal relationship between public sector's agricultural research expenditures and agricultural output in Lesotho, then
- if there is any relationship, to analyse the structure (i.e. whether the relationship is one way or whether it is a feedback relationship) and stability of this relationship over time,
- if there is a relationship, to determine the lag length between spending on research and its impact on agricultural output and productivity, and
- to determine if there is a causal relationship between the relative importance of agriculture to the whole economy and the allocation of public research funds to agriculture.

1.4 Hypotheses

1. There is no causal relationship between public sector agricultural research expenditure and agricultural output.
2. There is no feedback relationship between output and research.
3. There is instability in the relationship between research and output over time.
4. There is no causal relationship between the relative importance of the agricultural sector to the whole economy and the allocation of public funds to agriculture.

Hypotheses 1 and 2 were meant to address the first and second objectives while hypotheses 3 and 4 were meant to address the third and fourth objectives respectively.

1.5 Study Rationale

In Lesotho a large proportion of agricultural research is funded from donor sources, mainly USAID. The government of Lesotho has always been accused of underinvesting in agricultural research (ISNAR 1989, 'Matli 1995 (pers. comm.), MACM 1992). This might be due to the fact that the government has not yet realised the importance of spending on agricultural research. The motivation of this study therefore lies in establishing whether there is any relationship between funds invested in agricultural research and agricultural productivity and, if there is a relationship to demonstrate to the GOL the critical importance of recognising agricultural research as the driving force of growth of the agricultural sector. Moreover, given the instability of donor funding, it may be important not to rely heavily on this source for funds for agricultural research as is the case now.

A few studies made in Lesotho on the relationship between agricultural research and output focused on the analysis of the consequences of technical change (for example, Namane 1991). Not much has been done on the explanation of the observed rate and direction of an inventive activity. The second motivation of this study was spurred by an interest to bridge this gap. Because a substantial proportion of agricultural research in Lesotho is undertaken by the public sector[1] the dynamics of public sector research, in particular publicly sponsored agricultural research in Lesotho is analysed in this study.

1.6 Outline of the Study

In the next chapter a survey of previous studies of the relationship between research and output in agriculture and other sectors is made. The review covers international studies as well as studies made in Southern Africa. The studies in other countries, mainly in LDCs, are particularly important in providing valuable comparisons since

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[1]The concept of the public sector in this study is taken to include government, semi-public, and academic research institutes.

there are a few publications relevant to the Lesotho case. This study can therefore be seen as an attempt to fill the gap in the literature in the case of Lesotho.

Chapter 3 reviews the previous models (or approaches) used to analyse the causal relationship between research expenditures and Total Factor Productivity (TFP) and the general model for Lesotho is identified. Also, the rationale for the identification of this model is discussed.

In Chapter 4, the main methodology adopted in this study is presented. The econometrics characteristics of the approach identified in chapter 3 as well as the econometric estimation techniques that are employed by the approach are explained. The data used in the study are also described. Moreover, data pre-whitening process is carried out in this chapter. This is in the form of unit-root tests. Cointegration tests are also performed in this chapter.

In chapter 5 the model suggested by cointegration tests is specified and appropriate lag length based on the specified model is determined. Then, the appropriate (specific) model which fits the data best is identified, estimated and causality tests are conducted. The results and their interpretations are also provided in this chapter. Last but not least, conclusions, policy implications, limitations of the study and suggestions for further research are presented in chapter 6.

2. Related Literature

2.1 Introduction

This chapter consists of a survey of previous studies of the relationship between research and output in agriculture and other sectors. Important contributions of previous studies on causality and lag formulations are considered. Although there is much literature concerning the analysis of the consequences of technical change and explanation of the observed rate and direction of inventive activity, a large proportion of this literature relates to studies done in developed countries, mainly the United States of America. Very few studies were done in LDCs, none relate directly to Lesotho which is the major concern in this study. Consequently, the literature covered in this chapter does not include any studies concerning Lesotho. Section 2.2 deals with the literature on causality between research expenditures and productivity change in both the agricultural sector and the non-agricultural sector. Three broad schools of thought concerning causality are discussed in this section. Section 2.3 deals with lag problems encountered in the previous studies of the relationship between agricultural research expenditures and agricultural output.

2.2 Theory of Causality

Although there are numerous studies of the rate of return to agricultural research and development (R & D) expenditures, there have been few attempts to establish causality between total factor productivity (TFP) and the variables that might influence TFP growth. Examples of these few studies are Pardey and Graig (1989), Hallam (1990) and Schimmelpfenning and Thirtle (1994). Nevertheless, from the literature three broad schools of thought concerning the relationship between research and output can be identified, viz., a supply-driven, or science based view, a demand-driven or endogenous technical change perspective and the view comprising a feedback relationship.

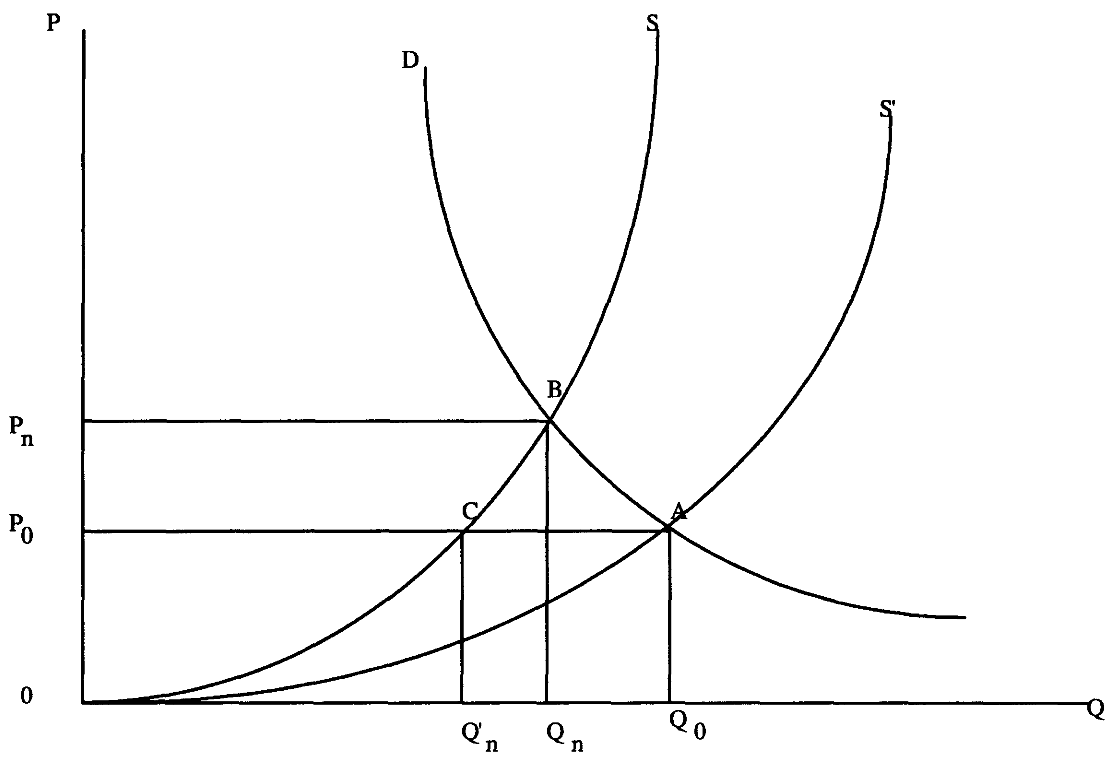
2.2.1 Supply-driven causality

Economists have formalised the notion of supply-driven causality into traditional production function models, where an industry's final output is a function of conventional inputs (factors of production) such as labour and capital, along with novel inputs such as research expenditures. This view takes technological change as an exogenous variable. Consequently, there is an implicit assumption that research expenditures are causally prior to output in the sense of Granger (1981).

Examples of these studies include early studies of the US agricultural sector by Minasian (1969), and more recent studies by Ruttan (1982); Bonnen (1983) and Rose-Ackerman and Evenson (1985). Also, there are more recent studies of the UK agricultural sector by Thirtle and Bottomley (1989); the Bangladesh agricultural sector by Pray and Ahmed (1991); the Indian agricultural sector by Evenson and McKinsey (1991); and the Zambian agricultural sector by Howard, Chatula and Kalonge (1993). However, the latter was based on single crop analysis while the rest were based on the agricultural sector in general. Nevertheless, the objective was the same in all cases. In all these studies, an attempt was made to calculate returns from public agricultural research expenditures.

The economic rationale of the approach employed in these studies lies in the technology-push hypothesis. Working from Marshall's economic surplus paradigm, these studies hypothesised that the essential impact of agricultural research is to raise productivity, causing the aggregate supply function to shift outward from S to S' (Figure 2.1) [see Akino and Hayami 1975 and Traxler and Byerlee 1992]. Assuming a closed economy model, if the market is in equilibrium, the benefits from the supply shift are represented by the area ABO. The price elasticities of demand and supply determine the relative benefits gained by producers and consumers. In Figure 2.1, the change in producer surplus = AOC - $P_n BCP_0$.

Figure 2.1: Supply shift from research and related investments



Source: Howard and Kalonge 1993, p.9.

The additional social surplus created by the outward shift in the supply curve represents the gross benefits arising from investments in research and related investments. Based on the graph, to estimate the average rate of return (ARR), net benefits for each year (or other relevant time period) are calculated by subtracting research expenditures from the gross benefits for that year. Society's net benefit from the agricultural research effort is therefore, the difference between the research-induced change in variable profit and the cost of the research. The most commonly used indicator of the efficiency of research investments is the internal rate of return (IRR) which Gittinger (1982) describes as the maximum interest rate that a project could pay on the resources invested and still break even.

2.2.2 Demand-driven causality

This view is based on the "demand-pull" hypothesis. Innovation is considered as an endogenous variable influenced by market demand. In this view attention is devoted to the factors that influence the rate and direction of innovation rather than the description of the consequences of technical innovation as it is the case with supply-driven causality. Hence, the governing influence upon the innovation process is that of market demand. Innovations are in some sense "called forth" or "triggered" in response to demands for the satisfaction of certain classes of "needs" (Mowery and Rosenberg 1979). According to this view, market demand is seen to play an indispensable role in the development of successful innovations. This means that an innovation[1] is introduced because the demand for a product has increased (i.e. the demand curve has shifted outward from D to D') and its relative price has risen as shown in Figure 2.2. This is reffered to as the induced innovation hypothesis. Advocates of this view include Mowery and Rosenberg (1979), Rosenberg (1982), Bosworth and Westaway (1984), and Oehmke (1986).

Some what separate literatures concerning the demand-pull causality have emerged - one centred on private and the other on public demand. The pioneering work of Schmookler (1966) gives a detailed empirical account on the private demand case. In his analysis of the association between investment and capital goods invention in the American private sector, he used both time-series and cross-sectional data on investment and patenting for railroads, building, and petroleum refining (Chapters VI and VII). His main conclusion from the study was that demand played a leading role in

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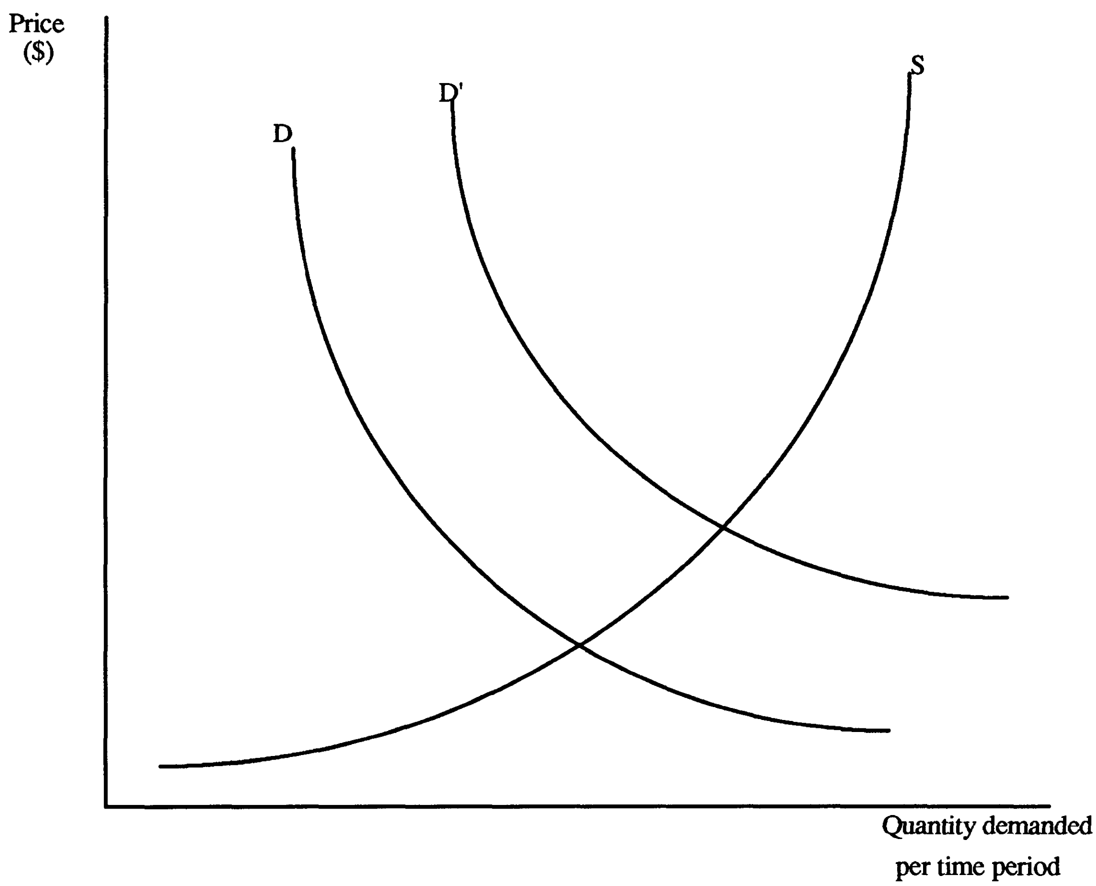
[1]Innovation in this case refers to the influences upon the allocation of research and development inputs.

determining both the direction and the magnitude of inventive activity. He demonstrated a rough proportionality between investment (which he proxied by value added) and successful patent application for capital goods inventions filed in the

Figure 2.2: Demand shift from increased demand of agricultural inputs



Source: Mowery and Rosenburg 1982, p. 230.

succeeding three years. This, he concluded, showed a strong evidence of demand-induced invention. Scherer (1965, 1982) and Rosenberg (1974) share the same view.

The potential underlying premise of these studies' results is that the larger an actual or potential market is, the more inventive activity will be directed toward it, partly because the profitability of invention rises with market size, *ceteris paribus*. In other words, potential gains from successful inventive activity, as indexed by expected market size for the output of R & D activity, drives inventive activity at the firm or industry level.

Griliches and Schmookler (1963) and Schmookler (1966) emphasise the importance of expected market size as an inducement to research effort. They recognise that the inventive activity is guided by the expected value of the solution to technical problems, and therefore, that the private return to research varies directly with the number of units of output embodying the research knowledge or with the size of the market, see also Rosenberg (1982).

As other determinants of research demand, another facet of literature identifies the degree to which firms can appropriate the benefits from the industrial knowledge they produce. Relevant here are the technical opportunities facing firms that reflect the set of production possibilities for transforming research sources into innovations as other determinants of research demand (Pakes and Schankerman 1984).

This view provides a clear flow of causality running from output to private research activity. However, this view relates to situations in which the returns from research are enjoyed or rather appropriated by the firm or the institution directly undertaking or investing in research. On the contrary, in public agricultural research there is a distance between agencies or institutions directly engaged in research or research investment and the beneficiaries of research knowledge who are farmers. In this regard public demand models of inventive activity have had limited attention. Thus, as Pardey and Graig (1989, p. 10) contend, 'the mechanisms by which demand is estimated, and in particular the conditions of appropriability, largely distinguish private from publicly demanded research activity'.

Studies on public agricultural research activity which follow this view include American studies such as Guttman (1978), and Rose-Ackerman and Evenson (1985). They argue that public agricultural research demand is influenced by the voluntary contribution of research demanders (farmers and agro-industries) in lobbying activity either by voting or making campaign contributions in order to induce research allocations. That is, public agricultural research is believed to be influenced by political effectiveness of farmers, or farm interests. They also state that political participation by largest farmers/farm interests increases relative to participation by the smallest farms as the overall number of farms increases. Implicit in this argument is that agricultural output or sales lead publicly committed research expenditures (see also Peterson 1969, Huffman and Miranovski 1981). This cannot be applicable in the case of Lesotho since the farmers are not as vocal as they might be in developed countries. The reason being that most are subsistence farmers and to them agricultural research is remote. Consequently, the duty falls on the government through its trained staff to identify research needs of the farmers and to advocate for funds to be invested in agricultural research.

2.2.3 Feedback causality

This view involves possible feedback between output and research. It combines both the "demand-pull" and "technology-push" hypotheses of the research-output relationship and reveals the simultaneity between the two. In this view it is shown that 'while the scale of R & D activity affects the rate of growth of productivity , ... , the rate of growth, in turn, affects the relative cost of R & D and, hence its demand' (Baumol and Wolf 1983, p. 147).

The premise underlying this view is that relative productivity of manufacturers and R & D services are critical determinants of their relative prices. Consequently, success in R & D and the consequent increase in manufacturing productivity may raise the relative price of R & D, reducing the quantity demanded. Baumol et al. (1983) developed models of this feedback process and demonstrated how this feedback process can lead to oscillatory behaviour and to a slow down of the economy's long-run productivity. However, they did not empirically test the formal model. Grilliches (1979) reviewed the issue in general terms for private sector research activity.

Mairesse and Siu (1984) empirically tested for the feedback relationship between public research expenditures and productivity. In their study to investigate the determinants of both R & D and physical investment they found out that expected profitability of firms (measured in the study by the stock market one-period-holding rate of return) and the expected demand (measured by the rate of growth of sales) caused subsequent R & D and gross investment changes. However, no feedback relationship was observed from R & D and investment to either the firm'sexpected profitability or the expected demand.

Pardey and Graig (1989) and Schimmelpfenning and Thirtle (1994) did the same study for the agricultural sector. Pardey and Graig empirically tested for feedback relationship between public agricultural research expenditures and agricultural output using US data. In their analysis they came to the conclusion that there is a feedback relationship between the two. Schimmelpfenning and Thirtle (1994) did the same study, but using UK data. Although they used a short time series data (16 years) compared to the long series of 93 years used by Pardey et al., they came to the same conclusion as the latter.

In the case of Lesotho's public sector agricultural research, feedback would be consistent with an agricultural sector which benefits from technological innovations arising in, say, the Agricultural Division of Lesotho (which undertakes almost all of the country's agricultural research) and other public research stations in the country, and a system of these research stations whose funding depends upon the performance of the agricultural sector. While some researchers in Lesotho have empirically analysed the impact of technological change on the output of selected crops, the causal relationship between agricultural research expenditures and productivity and the feedback causality between the two has never been formerly tested. This study fills this gap using in-sample tests of causality suggested in the time-series literature (for example, Pardey and Graig 1989).

Productivity and research expenditure series normally have strong trends and establishing whether there is any relationship between them can be problematic. This problem has caused many studies analysing the returns from public agricultural research expenditures to agricultural sectors to be subject to criticism. It is argued that the relationship between research spending and productivity change realised in these studies might be a result of spurious regressions. To avoid this criticism, the question of whether there is a long-run relationship between productivity and research spending is explored in this study using the concept of cointegration (Engel and Granger 1987).

2.3 Lags

Much of empirical work concerning the relationship between agricultural research and output has been geared towards estimating marginal internal rates of return to agricultural research expenditures. In most of these studies, these rates of return were estimated under non-trivial assumptions as to the lag length between spending on research and its impact on agricultural output and/or productivity, as well as the structure and stability of this relationship over time.

In these studies there is a heavy reliance on imposed rather than tested priors when estimating the (aggregate) lag relationship between public research expenditures and output. Mostly a distributed lag structure was employed, normally an Almon inverted V or an Almon polynomial lag structure. An a priori assumption is usually made that the lag structure is a second degree polinomial. That is, initially the effect of R & D on productivity is expected to be small and then to rise to a peak before diminishing to zero as the new technology becomes obsolete. This lag structure was introduced in some of these studies because the majority of recent studies in this field adopted it (Thirtle and Bottomley 1989), and it was used mainly to circumvent problems of (a) serial correlation between lagged values of research expenditure, and (b) insufficient degrees of freedom (see Cline and Lu (1976) and Knutson and Tweeten (1979) for the US data and Hastings (1981) for Australian data). However no formal tests were performed in these studies to justify either the lag length or the polynomial degree.

The fact that the lag structure in these studies has been introduced without the basis of some theoretically derived priors has subjected these studies to the criticism that the high rates of return obtained from research expenditures are due, at least in part, to the imposition of questionable restrictions on the form of the distributed lag between research expenditures and productivity change (Hallam 1990, Pardey and Graig 1989). Another criticism applied to these studies is that while low-order moments of a lag distribution such as its mean and variance, might be estimated with greater precision, the lag coefficients may not (Hatakana and Wallace 1980), and thus the implied internal rates of return to agricultural research advocated by these studies may not be true because of their sensitivity to the partial research production coefficients derived from models estimated with inappropriate lag structures (Pardey et al. 1989).

Another criticism of models based on imposed lag structure is associated with severe problems of biasedness and inconsistency of estimates and invalid tests resulting from the wrong choice and specification of polynomial degree and length. These are evident in Frost (1975), Schmide and Wauld (1973), Pagano and Hartley (1981). Hence, the Almon restrictions should be tested. However, as mentioned earlier on, no formal tests were performed in these studies.

Some studies (Thirtle et al. 1989) imposed zero-endpoint restrictions on the Almon lag distribution to get a more plausible lag distribution. Endpoint restrictions constrain the lag distribution to zero at lags of t+1 and t-(n+1), where t is the current time period and n is the maximum lag length specified. However this procedure is very restrictive. It is now generally recognised that the endpoint constraints are not necessarily valid empirically and that they can tend to distort what might otherwise be an appropriate lag distribution. Also, endpoint restrictions lack theoretical rationale (Schmidt and Waud 1973).

In this study, although the time series of data is not very long, an attempt is made to address the issue of lag length. To avoid the criticism of restrictive lag structures, lag structures of research expenditures and productivity change are empirically determined in this study using the Akaike Iformation Criterion (AIC) and the Swartz Criterion (SC) statistics. A substantial number of studies have proceeded with finite lag structures involving lag lengths in the twelve-year range (Thirtle and Bottomley 1989), while some proceeded with lags as short as six years (Schimelpfenning et al. 1994). The empirical evidence to support these maintained hypothesis is rather thin. As mentioned earlier on, the lag lengths in some of these studies were chosen only after a substantial structure had been imposed on the form of the lag relationship in the context of models which did not admit the possibility of feedback between output and research expenditures. Their models were based on single equations. However, as Pardey et al. (1989. p.11) point out, "it is important to recognise that consistent estimation of the lagged effect of research on output using single-equation techniques can be guaranteed only if lag length is correctly specified and simultaneity is ruled out".

With more and better US data, Pardey et al. (1989) investigated the appropriate length of the lag and they came up with significantly longer lags than those commonly used for agricultural research to date. They found out that the long lags of at least thirty years may be necessary to capture all of the impact of research on agricultural output in the US. They also used a bivariate system of equations to take care of possible feedback between agricultural research expenditures and agricultural output.

In the next chapter different approaches used by protagonists in the economic literature concerning the analysis of the relationship between agricultural research expenditures and agricultural output are reviewed. The general model for Lesotho is also identified.

3. Review of Related Models and Model Structure for Lesotho

3.1 Introduction

This chapter provides a review of the most common approaches used to evaluate public agricultural research investment in the economic literature. Different research techniques have been used in both *ex post* and *ex ante* studies. However, only approaches used in *ex post* studies will be considered in this study because of their relevance in this regard. Three major approaches employed by *ex post* studies can be identified, viz., (a) index-number approach (also known as consumer and producer surplus approach) (This approach is used for estimating average rates of return to research.), (b) production function approach, used for estimating marginal rates of return to research, and (c) cointegration and Granger causality tests approach, used for establishing the causal relationship between public agricultural research investment and agricultural output/productivity. The first two approaches are not directly related to the study in question. Their main objective is to measure returns to research and not to establish the causal relationship between research and output, as is the case in this dissertation. However, their (the first two approaches) review is crucial to the justification of the causality approach adopted in this study. Section 3.2 gives a detailed account of the index-number approach. In section 3.3 the production function approach is discussed, section 3.4 provides the cointegration and Granger causality tests approach, and last but not least, the general model for Lesotho is briefly discussed in section 3.5.

3.2 The Index-number Approach

The index-number approach, also called consumer-producer surplus approach, estimates the benefits to agricultural research by measuring the change in consumer surplus (CS) and producer surplus (PS) from a rightward shift in the supply curve brought about through technical change.

In this approach, agricultural research is conceptualised as the welfare problem in which both efficiency and equity contribute to social welfare and play the major role. In this case efficiency involves the magnitude of the social rate of returns to the investment, and equity involves the question of who captures the gain (and bears the loss). Equity effects are usually divided between the producers and consumers of agricultural products. The model employs the Marshallian concepts of social welfare and cost. Social returns to agricultural research are measured in terms of changes in consumer and producer surpluses resulting from a shift in the supply curve of agricultural production as a consequence of improved technology. Therefore, the assumptions made about the specification of demand and supply functions as well as on the shift of the supply function are crucial to the determination of the value of social returns. Most of the studies which follow the index-number approach evaluated the consumer - producer surplus at the commodity level. However, most if not all of them differ in the assumptions they make on the demand and supply function specifications and in the nature of supply function shifts. Consequently, even the formulas they used to compute the surpluses differ because they depend on the respective demand and supply elasticities and the supply shift parameters.

To demonstrate how the gains (or losses) to consumers and producers and thus social gains are computed, the early study of Peterson (1967) is used. Peterson (1967), in his attempt to measure the social gains accruing from poultry research, developed a formula that measures the value of consumer surplus generated by increase in poultry productivity as a consequence of innovations in poultry production. He used an indirect approach and started by questioning by how much the consumers of poultry products would loose if the poultry innovation were to cease (i.e., if the more efficient production methods brought about by new innovations in poultry production were to be abandoned). He demonstrated that when the price and quantity move from P_1 to P_2 and from Q_1 to Q_2, respectively (see Figure 3.1), the change in net economic surplus = A+B+C+E+G(-A-B+H+I+J) = C+E+G+H+I+J. He reasoned that this area is approximately equal to I+J+K+L+E+G-D and provided the following formula to approximate it:

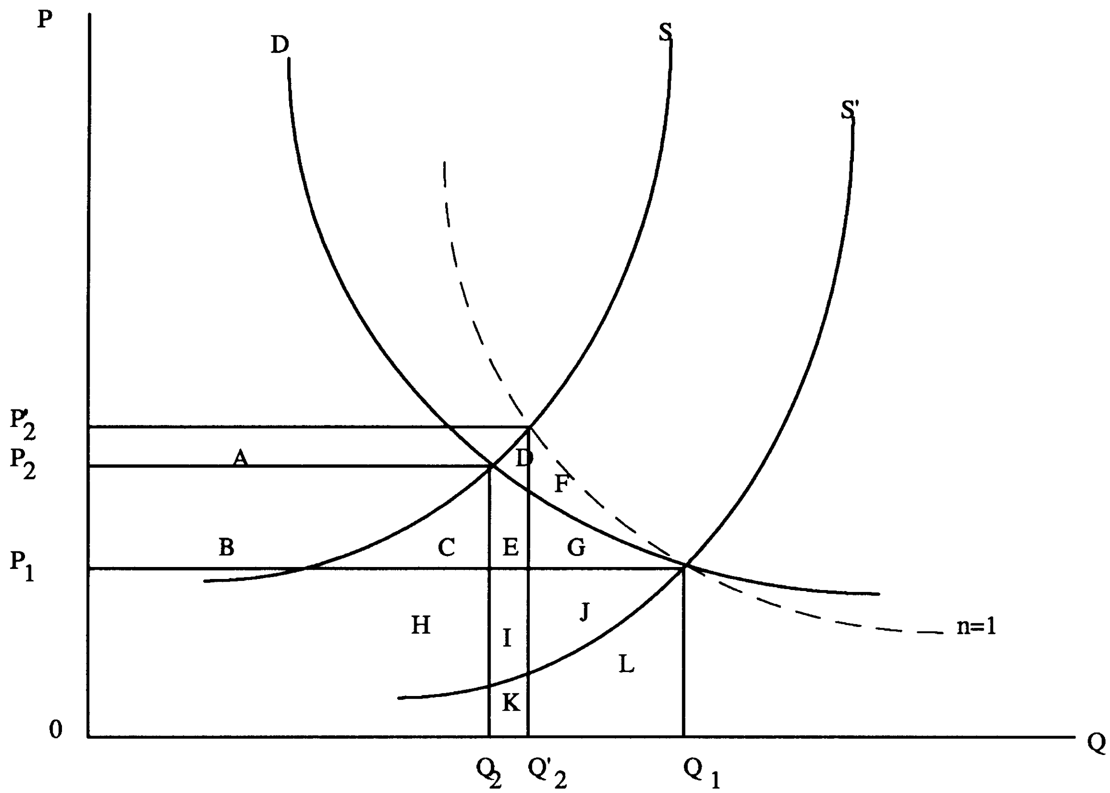
$$KQ_1P_1 + \frac{1}{2}K^2P_1Q_1 / n - \frac{1}{2}Q_2K^2P_2\left(\frac{P_1}{P_2}\right)\left(\frac{en}{n+e}\right)\left(\frac{n-1}{n}\right)^2 \tag{3.1}$$

where n is the absolute value of the demand elasticity, e the supply elasticity, and K the percentage shift in the supply curve (which he measured by $\frac{Q_1 - Q'_2}{Q_1}$). He compared this with costs of research and extension and calculated an internal rate of return. The above expression reduces to

$$KQ_1P_1(1 + K/2n) \text{ if n=1 or e=0} \tag{3.2}$$

In his analysis he assumed unitary supply and demand elasticities. He also assumed a parallel shift in the supply curve implicit in Figure 3.1. Schmitz and Seckler (1970) extended the model to account for the effect of the introduction of tomato harvesters in the US on the welfare of labourers released and production efficiency gained as a consequence of the introduction. They computed the net social returns as the value of inputs saved by the introduction of the new tomato harvester less the value of costs incurred by labourers displaced by the harvester. In calculating the net social benefits they first assumed the case of compensating the labourers for job loss and then the case of no compensation.

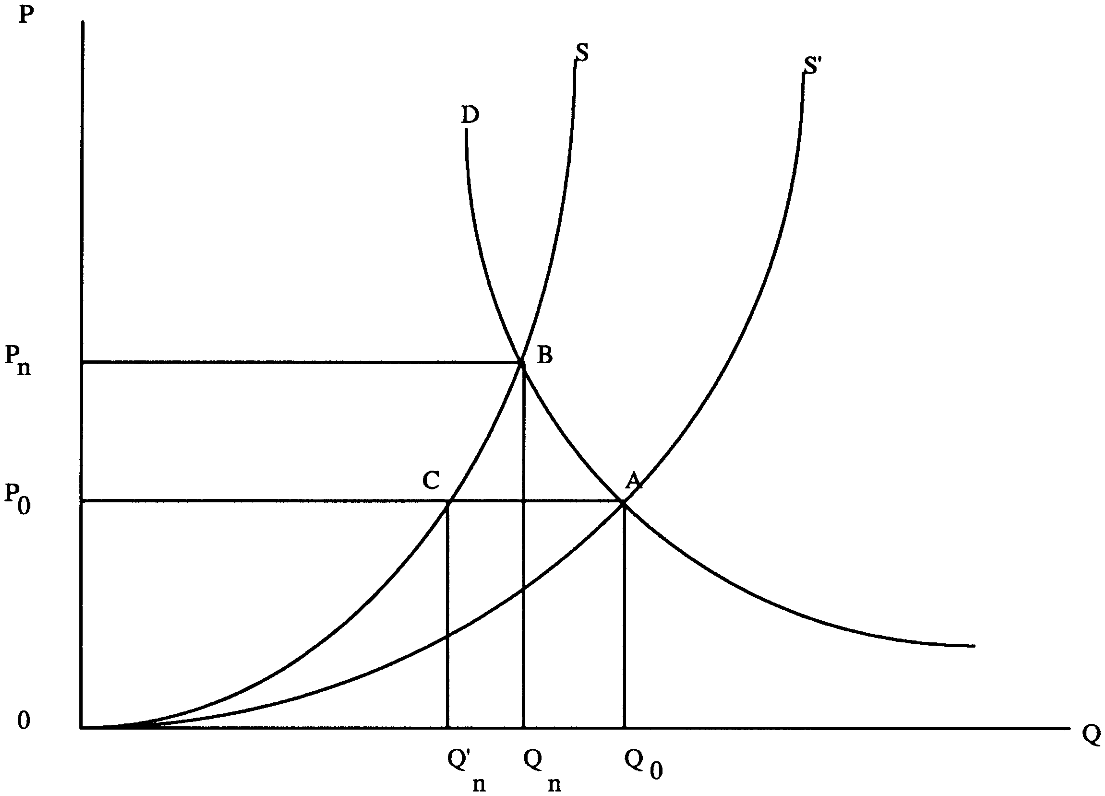
Figure 3.1 Poultry supply shift resulting from the use of new inputs



Source: Norton and Davis 1981, p. 687.

Other studies followed Peterson's study. To mention a few, Akino and Hayami (1975) used the same approach in their study to evaluate social returns accruing from rice breeding in Japan. Unlike Peterson, they assumed a constant elasticity of demand and supply. They also assumed a pivotal shift in the supply curve (see Figure 3.2). Based on the demand and supply model represented in Figure 3.2, Akino and Hayami (1975) developed the following formulas to compute the social rate of returns to public investment in the rice breeding research and the distribution of the returns

Figure 3.2: Rice supply shift due to breeding research



Source: Akino and Hayami 1975 p. 4.

among producers and consumers in Japan. The formulas are for estimating areas P_nBCP_0, ABC,AOC and ACQ'_nQ_0:

$$P_nBCP_0 = P_0Q_0\frac{K(1+e)}{e+n}\left[1-\frac{\frac{1}{2}K(1+e)n}{e+n}-\frac{1}{2}K(1+e)\right]n$$

$$ABC = \frac{1}{2}P_0Q_0\frac{[K(1+e)]^2}{e+n}$$

$$AOC = KP_0Q_0$$

$$ACQ''_n Q_o = (1+e)KP_0Q_0$$

where K is the shift in the production function. The shift in the supply function can be approximated by (1+e)K. Howard, Chitalu and Kaloge (1993) adopted Akino et al.'s formulas to compute the net social gains to the maize variety improvement in Zambia.

Although the approach has been used extensively it the literature, it has received much criticism. Linder and Jarett (1978) point out that the returns calculated based on this approach are based on non-trivial assumptions concerning the supply shift and the supply intercepts. In their analysis they demonstrate the sensitivity of gross average research benefits to the assumptions made about the shift in the supply curve. Their contention is confirmed by Duncan and Tisdel (1971) where they show that the nature of the supply shift is the key determinant of the distribution of benefits from research between producers and consumers. Linder et al. (1978) discovered that the convergent shift in the supply curve leads to more benefits compared with the pivotal, proportional and parallel shifts. Consequently, results based on the index-number approach could be biased except in cases where the supply curve is highly elastic over the interval back to the vertical axis in which case the measured level of research benefit is much the same for both a proportional and parallel shifts. This is in line with the limiting case where supply is perfectly elastic. In this case a proportional shift will also be a parallel shift. They also demonstrate the importance of testing the sensitivity of measured research benefits to various assumptions about the value of the intercept term of the supply curve, an element which is lacking in the studies which employed the index-number approach.

The index-number approach is mostly/if not always used for commodity-based studies. They have thus received criticism as not being representative, since they tend to concentrate on prominent and successful innovations and fields (Grilliches 1986). For more general cases the econometric production function approach has been employed. It tries to meet these objections by abandoning the interesting detail of specific events and concentrating instead on total output or total factor productivity (TFP) as a function of past research and development (R&D) investments and other variables. The next section provides a discussion on the production function approach.

3.3 The Production Function Approach

Production functions have been fitted in the economic literature with a view to identifying the marginal returns to R&D input. Unlike the index-number approach, the production function analyses are usually at a higher level of aggregation, i.e. total agricultural output is usually expressed as a function of aggregate R&D expenditures and other variables. Because of the lagged effect of technical change resulting from investment in research and development, time series data are required in this type of study. However, time series data of agricultural inputs pose the well known problems of collinearity. This problem has been circumvented in the literature by dividing inputs into two groups, conventional and novel inputs, and disposing of the conventional inputs by incorporating them in a TFP index. The conventional inputs in this case are such traditional inputs as land, labour, machinery, buildings, chemicals and other miscellaneous inputs. The novel inputs on the other hand are such inputs as R&D expenditures, education, weather index and other variables which are taken to be influenced by agricultural policies which indirectly influence productivity growth.

The high level of aggregation in computing the TFP (which is the ratio of aggregate output index and aggregate input index) requires severe separability assumptions concerning the inputs. That is, for consistent aggregation, the input groups must be functionally separable (Berndt and Christensen 1973). The methods which are usually used in the literature to compute the output and inputs aggregates are the Tornqvist-Theil discrete approximation of the continuous Divisia index (which is exact for the translog production function) and the arithmetic index (which is exact for the linear production function). However, many studies have employed the former approach.

The basic model used in the production function (PF) approach has been

$$Q_t = \prod_{i=1}^{m} X_{it}^{\beta_i} \prod_{j=0}^{n} Z_{jt}^{\alpha_j} \tag{3.3}$$

where

Q_t is aggregate output, (composed of q_{ht}), X_{it}'s are traditional inputs and the Z_{jt}'s are novel inputs and the β_i's and α_j's are parameters. If the Divisia is used to aggregate the outputs q_{ht} and the conventional inputs X_{it}, then,

$$\begin{aligned} \ln(TFP_t / TFP_{t-1}) &= \frac{1}{2}\sum_h (R_{ht} + R_{h,t-1})\ln(q_{ht} / q_{h,t-1}) \\ &-\frac{1}{2}\sum_i (S_{it} + S_{i,t-1})\ln(X_{it} / X_{i,t-1}) \end{aligned} \tag{3.4}$$

where the q_h are output indices, the X_i are input indices, the R_h are output revenue shares, the S_i are input cost shares and ln denotes natural logarithms.

The equation (1) can be written in the TFP form as

$$\ln P_t = \ln(TFP_t / TFP_{t-1}) = \ln\left(\prod_{j=1}^{n} Z_{jt}^{\alpha j}\right) \tag{3.5}$$

Adding the constant term (A) and the stochastic error terms gives the 'conventional' model,

$$P_t = A\prod_{j=1}^{n} Z_{jt}^{\alpha j} e^{\mu_t} \tag{3.6}$$

where Z_j's are normally lagged research expenditures R_{t-j}, extension services (EX), farmer education (E), and weather index (W). Taking the logarithms of equation (4) and substituting the above novel inputs for Z_j results in the linear equation

$$\ln P_t = \ln A + \sum_{i=0}^{n} \alpha_i \ln R_{t-i}^{i} + \beta_1 \ln EX + \beta_2 \ln E + \beta_3 \ln W + \mu_t \qquad (3.7).$$

Although the Divisia index approach used in aggregating outputs and inputs is exact for the traslog function, equation (3.5) is specified as log-linear, implying a Cobb-Douglas function as far as the inputs are concerned. This is done mainly for ease of manipulation purposes. A distributed lag structure is often assumed in this approach to circumvent problems of serial correlation (inherent in the lagged values of research) and degrees of freedom. This is normally an inverted V or an Almon polynomial lag structure. Studies which have followed this approach include Evenson (1967), Hastings (1981), Thirtle et al (1989), Grilliches (1986), Hallam (1990). Other studies which followed this approach are given in the Literature Review chapter.

Although the approach is an improvement to the index-number approach, it also suffers severe criticisms. The results obtained under this approach are based on non-trivial assumptions, rather that tested priors, concerning the relationship between research expenditures and output, and the lag structure of the research expenditures. Causality between agricultural research expenditures and agricultural output (productivity) is assumed. Also, it is assumed that the relationship between the two is supply-driven rather than demand-driven. The lag structure of the model is imposed rather than formally tested. Consequently, the results based on this approach have been criticised as spurious. Pardey et al. (1989), Hallam (1990), and Schimmelpfenning et al. (1994) have recently adopted a different approach which formally tests for the causality between research expenditures and output (productivity) in the Granger sense, and which takes care of the simultaneity between the two. Pardey et al. went further to test formally for the appropriate lag structure of research expenditures. The following section provides a discussion of the cointegration and Granger causality tests approach.

3.4 Cointegration and Granger Causality Tests Approach

The problems inherent in the estimation of time series models are a burning issue in the econometrics literature these days. The concern has been spurred by the recognition that many studies report econometric results which are based on spurious regressions. As Granger and Newbold (1974, p. 111) contend:

> It is very common to see reported in applied econometric literature time series regression equations with an apparently high degree of fit, as measured by the coefficient of multiple correlation R^2 or the corrected coefficient $\overline{R}^2$, but with an extremely low value for the Durbin-Watson statistic.

Low values of the Durbin-Watson statistic is a warning signal of autocorrelated residuals of the model and of a spurious regression. The autocorrelated residuals are more common with time series data. Three major consequences of autocorrelated errors in regression analysis have been identified as, (i) estimates of the regression coefficients are inefficient, (ii) forecasts based on the regression equations are sub-optimal, and (iii) the usual significance tests on the coefficients are invalid. To overcome these weaknesses Pardey et al., Hallam, and Schimmelpfennig used cointegration and Granger causality tests approach to formally establish the relationship between agricultural research expenditures and agricultural output.

The approach involves a number of steps. First, individual series have to be tested for stationarity. Second, if integrated, they should be tested for cointegration. Finally, if cointegrated the error correction model has to be specified, estimated and tested for Granger causality.

3.4.1 Causality tests

Causality tests are based on the test proposed by Granger (1981). The test hinges on the idea that random variable, say, x is causally prior to random variable, say, y if the past history of x improves significantly our ability to predict series y compared with our ability to predict y using all the relevant information apart form x. Under these circumstances x is said to Granger-cause y. If x Granger-causes y and y Granger-causes x the process is called a feedback system.

In the definition of causality used here, a decision must first be made about what information will constitute the set of all information relevant to the prediction of a particular random variable. For example, in the case of x causing y, it must be decided on what information will constitute the set of all information on x. Studies which are reviewed in this section employed the use of a bivariate system such as equation set (3.8) in their analyses:

$$y_t = a(L)y_t + b(L)x_t + \varepsilon_{yt} \qquad (3.8a)$$

$$x_t = c(L)y_t + d(L)x_t + \varepsilon_{xt} \qquad (3.8b)$$

where variables x and y are covariance stationary processes with autoregressive representation, i(L) is a polynomial of degree v in the lag operator, i.e.,

$$\text{i(L)}\, Z_t = \sum_{k=1}^{v} i_k z_{t-k}$$

where i=a, b, c and d.

Using the definition of causality given above, x causes y if any coefficient b is non-zero; y causes x if any coefficient c is non-zero; and a feedback occurs between x and y if both b(L) and c(L) have non-zero coefficients.

3.4.2 Studies which employed Granger causality approach

Hallam (1990) applied cointegration and Granger causality techniques on the UK series which was previously used by Thirtle and Bottomley (1989). In his analysis he attempted to determine if TFP was causally related to research expenditures in the Granger sense on the one hand, and TFP and other variables like extension expenditures, farmer education and a weather index on the other hand. However, he failed to establish any causal relationship between public agricultural research expenditures and all the other variables. The main reason to which his failure can be attributed is the shortness of the series he considered. He used a series of only 16 observations from 1967 to 1987. Also, in his series pre-whitening process, he tested for unit root of the series using the Durbin-Watson statistic (CRDW) and Augmented Dickey-Fuller (ADF) tests without considering the possibility that a series could be a trend stationary process (TSP) or a difference-stationary process (DSP) and yet this distinction is critical to subsequent analysis of the relationship between different data series (Lloyd and Rayner 1993).

Schimmelpfenning (1994) used the same data used by Hallam (1990) to test the validity of the results obtained by Hallam. Unlike Hallam, in their stationarity tests process they differentiated between DSP and TSP processes. However, they found that all the series were pure random walks without any trends or drifts. Also, they used a rather powerful test based on the estimation of all cointegrating vectors, namely, the Johansen Maximum Likelihood estimation method. In this method they employed both the eigenvalue and trace tests. Based on both tests they were able to establish that the TFP and R&D series as well as TFP and research and extension were cointegrated if the maximum of six lagged values (VAR=6) were included. This, they argued, testified the theoretical literature which argues that the peak effect of R&D on TFP does not occur until after six or seven years. However, the shortness of their series prevented them from establishing formally the appropriate lag length of R&D.

After performing the cointegration tests they performed Granger-causality tests on the cointegrating vectors. Unlike Hallam, they found out that R&D was Granger-prior to TFP. They extended their application to the pooled series of ten EC[1] countries and the USA individually. This was done in an attempt to circumvent the problem of the shortness of the series encountered with the UK series and to incorporate the spill-over effects of research technology from some countries to others. For the pooled series they found out that a feedback relationship between TFP and R&D existed. This result

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[1] The "ten" are Belgium, Denmark, Eire, France, Germany, Greece, Italy, Luxembourg, the Netherlands and the UK. Luxembourg is included with Belgium.

poses a doubt on the adequacy of the traditional single equation approach (production function approach) to investigating the returns to R&D. Nevertheless, there is a danger in accepting the conclusions made in these two studies. Pardey et al. (1989, p.12) show that there is a great danger of making conclusions about causality from a bivariate model. This lies in the omission of relevant variables, particularly variables which may cause the two variables being considered. In this particular case, they point out, the most obvious omissions are conventional agricultural inputs such as land, labour, fertiliser, feed and others as well as private sector research which has application to agriculture. In these two analyses this aspect was not considered.

Pardey and Graig (1989) used a long time series for the USA and found that R&D expenditures were-Granger prior to productivity growth and that productivity also caused R&D expenditures. In their analysis they used three measurements of output to avoid likely omissions of variables which may be causing output other than the public agricultural research expenditures. They used output indices as the first proxy, TFP as the second proxy and the residuals of a regression of output indices on input indices as another proxy. The latter was used to capture the impact of other inputs other than conventional inputs on agricultural productivity. The fourth proxy, which was used to determine if R&D expenditures were supply- or demand-driven was the agricultural contribution to GNP.

Pardey et al.'s work was superior to those of the latter two in a number of respects. They formally tested for the appropriate lag length of the R&D using the Bayesian estimation criterion (BEC) and Akaike's final prediction error (FPE). The rationale for using these two approaches was based on the fact that although the BEC criterion has superior asymptotic properties in that it will neither over- nor underestimate lag length in a sufficiently large sample, it may underfit models. That is, it may select lag lengths which are too short in small samples. Rather than basing their results on in-sample tests only (as it was done in the latter two studies) they used both the in-sample and the out-of-sample tests of Granger causality between R&D and TFP. The use of post-sample test renders Pardey et al.'s approach better than those of Hallam and

Schimmelpfenning since the out-of-sample forecasting performance of the model relating to the original series provides the best information bearing on hypotheses about causation (Ashley, Granger and Schmalensee 1980).

3.5 General Model Structure for Lesotho

In the case of Lesotho, an attempt is made to establish the causal relationship between TFP and research expenditures. Like in the previous studies, all the steps involved in the cointegration and Granger causality tests approach are followed. Also, a bivariate system is adopted in the analysis. The approach adopted here hinges on the approach that was employed by Pardey et al. (1989). However a few changes are in order to adapt the approach to the situation of Lesotho. The changes are mainly in relation to the output measurements.

In this analysis two measures of output are used. The first one is the agricultural output index. It was the researcher's intention to use the other two output measures that Pardey et al. employed. However, because of data problems these two measures cannot be used. Instead, to measure the presumed technological impact of agricultural research on agricultural output, a partial measure of productivity in the form of yield is used. This is indeed a crude measure since it attributes growth in agriculture to only one, albeit the major, input, land. The third measure which is used to determine if R&D expenditures are demand-driven in Lesotho is the agricultural contribution to GDP.

3.5.1 Justification for partial productivity measure

The standard productivity index used for agricultural (mainly crop) performance is production per hectare, or yield. Yield increases can be obtained by the use of more inputs such as fertiliser and labour per hectare. In Lesotho land is the major constraint to agricultural production (see Chapter 1). Therefore, fertiliser is substituted for increased land by making the available land more productive (BOS 1994a). Other important factors are improved seed, pesticides, herbicides and good crop management, all of which reflect technological change in input usage. In this specification land plays a major role which comprises a measure of productive services from land, measure of land expansion and contraction effects (i.e. where land quality for new plantings may differ from the average land quality for the commodity). Also, because it is correlated with other 'left out' inputs such as the ones mentioned above, it is believed that it may 'pick up' their effects. Salmon (1991) demonstrates the appropriateness of using partial productivity measure based on the input which is the obvious constraint (also see Evenson and McKensey (1991)).

Since land is the obvious constraint on agricultural output growth in Lesotho, it is appropriate to focus on the partial productivity of land. That is, output per hectare. However, it is also imperative to mention the severe problems that partial productivity measures suffer. As Salmon (1991) contends, as farming practices improve, measures of partial productivity usually become less appropriate. For example, it may be hard to consider an increase in output per hectare a success if it is accompanied by a fall in labour productivity. Under these circumstances it is important to consider TFP since by aggregating and considering all important inputs to production, it becomes possible to account for growth in agricultural output more completely. Nevertheless, this cannot be done in this study because of lack of data on major agricultural inputs in Lesotho.

3.5.2 Unit root and cointegration tests

Some studies in the literature have used the Durbin Watson statistic and the Dickey-Fuller tests to test for the presence of a unit root in the series. However, as Davidson and Mackinnon (1993) contend, these tests are only valid under the assumption that the error terms in the test regressions are serially uncorrelated. To overcome this problem, in this analysis the Augmented Dickey-Fuller (ADF) and the Phillip-Perron (PP) tests are used. These tests are asymptotically valid in the presence of serial correlation of unknown order. To test for cointegration the ADF and PP tests will be applied on the regression residuals. To test for Granger causality the Wald test and the usual t-test will be used.

3.5.3 Lag determination

Many related studies in the literature used imposed lag structures without prior tests (See Chapter 2). In this analysis the Akaike Information Criterion (AIC) and the Swartz Criterion (SC) are used to formally test for the lag lengths of the variables.

The following chapter presents the complete econometric model for Lesotho which includes the data pre-whitening processes. A discussion on the data base employed in the study is also provided.