4. Empirical Analysis

4.1 Introduction

In this chapter the econometric method employed in this study is discussed. It has been shown in a number of studies (Pardey and Graig 1989, Hallam 1990) that regression of output/TFP on factors which explain agricultural growth can only be correct if the variables involved are cointegrated. Otherwise, the regression becomes spurious. If two variables which are integrated of the same order have a linear relationship which is stationary, they are said to be cointegrated. Section 4.3 deals with unit-root tests to test for order of integration of the variables employed in this analysis, following which cointegration tests are performed in section 4.4. Cointegrated variables are best represented by an Error Correction Model (ECM). Section 4.5 thus discusses an ECM representation of the data. When analysing the impact of agricultural research expenditures on agricultural output, it is important to test for the appropriate length of time it takes for agricultural research to have a significant impact on agricultural output/TFP. Section 4.6 discusses lag length tests. Implicit in the cointegration concept is that there is Granger causality between the two variables in at least one direction. Section 4.7 discusses the concept of Granger causality. The data employed in the study are discussed in section 4.2. All the regressions in this study have been performed through the use of the SHAZAM statistical package.

4.2 Data Requirements

It has been observed that there is a danger in drawing conclusions about causality from a system of equations because of the possible omission of relevant variables, particularly variables which may cause all the variables being considered (Pardey et al. 1989). When measuring the effect of public sector agricultural research on agricultural output, the most obvious omissions are conventional agricultural inputs such as land, labour, fertiliser, seed, and livestock plus private sector research which has applications to agriculture. To deal with the contribution of conventional inputs to agriculture, two measures of agricultural output have been used. These measures are meant to remove, explicitly or implicitly, qualitative changes in inputs. The first measure is the output index. This measures constant values of total agricultural output of Lesotho deflated by GDP deflators using 1985 as the base year. There are 32 (1961-1992) observations.

The second measure, as explained in Section 3.5.1, is yield. The intention was to use total factor productivity as the second measure, but because of the problems mentioned in Chapter 3 this could not be done. Also, a third measure of output which was meant to capture the contribution of novel inputs other than public agricultural research contribution to agricultural growth was intended to be used. This was going to be measured by regressing TFP on agricultural conventional inputs and using the residuals from this regression as the third measure of output, but because of the same problems mentioned in Chapter 3, this could not be done. Yield is measured as tonnes of major agricultural crops in Lesotho per hectare of land. The series consists of annual observations from 1965 to 1992.

The third proxy of output which corresponds more closely to a measure of agriculture's relative importance to the whole economy, is agricultural contribution to GDP. This measure is meant to provide additional information about research funding driven by demand. It comprises constant values of GDP contributed by agriculture, deflated by GDP deflators using 1985 as a base year. The data series is from 1964 to 1992.

Research expenditure is the dependent variable, and comprises total research funds contributed by the Lesotho government and the major donor agencies towards public agricultural research in the country. The data are in constant values, deflated by GDP deflators using 1985 as a base year. The series extends from 1961 to 1992.

All the data have been transformed into logarithmic form. This is due to the fact that most empirical time series exhibit the problem of variation that increases in both mean and variance in proportion to the absolute level of the series (non-stationary series). This poses a problem, since regressing non-stationary series which are not cointegrated results in a spurious regression. The logarithmic transformation is generally adequate, although the type of transformation required depends ultimately on the severity of the trend in the variance. However, given that most time series are I(1), as a rule of thumb, any I(1) series should be transformed into logarithms since differencing logged series produces better results than raw data (Lloyd and Rayner 1993).

The data used were secondary data obtained from the following sources: (a) Beintema, Pardey and Roseboom (1995) (research expenditures data), (b) Lesotho Agricultural Situation Reports (yield data), (c) FAO Production Yearbooks (output data) and (d) World Tables (GDP data).

4.3 Unit-Root Tests

Unit-root tests were completed to discover the underlying data generating process (DGP). The Augmented Dickey-Fuller and Phillip-Perron tests were used to test for unit roots in the series. The two tests have been used in favour of other tests (for example, the Dickey-Fuller and the Durbin-Watson tests) because they account for residual correlations and heteroskedasticity which might be present in the error term. The main objective in doing the tests was to distinguish between the following alternative data generating processes:

$$\Delta x_t = \alpha^* x_{t-1} + \mu_t \;\Rightarrow\; \text{DSP} \tag{4.1}$$

$$\Delta x_t = \delta + \alpha^* x_{t-1} + \mu_t \;\Rightarrow\; \text{TSP} \tag{4.2}$$

$$\Delta x_t = \delta + \beta t + \alpha^* x_{t-1} + \mu_t \;\Rightarrow\; \text{mixed process} \tag{4.3}$$

where $\alpha^* = \rho - 1$, DSP is a difference stationary process, TSP is a trend stationary process and 'mixed process 'is a process with both a trend and a drift.

Equations 4.1 and 4.2 are nested in equation 4.3, thus the tests are performed from equation 4.3 through to 4.1. Under the null hypothesis of a unit root, α^* is zero. If there is no unit root x_t is said to be stationary in levels, or integrated of order zero (denoted I(0)). If there is a unit root but differencing the series once makes it stationary, then it is said to be integrated of order one, denoted I(1) (Banerjee, Dolado and Hendry 1993). In addition to the unit root, equation 4.3 will establish if there is a deterministic trend $(\beta \neq 0)$ and/or a drift $(\delta \neq 0)$ (Davidson and Mackinnon, 1993). The error term μ_t should be white noise. If x_t is a first order autoregressive process (AR(1)), then the single lagged value of the dependent variable will be sufficient to ensure this condition. If the process is not AR(1), then m additional terms will need to be added to 4.3 to make the error term white noise (Enders 1995) and 4.3 becomes:

$$\Delta x_t = \delta + \beta t + \alpha^* x_{t-1} + \sum_{j=1}^{m} \rho_j \Delta x_{t-j} + \mu_t \tag{4.4}$$

where

$\sum_{j=1}^{m} \rho_j \Delta x_{t-j}$ = augmentation variables, and

m= the number of augmentation terms necessary to pick up all residual correlations.

Equation 4.4 is the equation for the augmented Dickey-Fuller (ADF) test. Augmentation variables are meant to pick up all residual correlations. The Phillip-Perron (PP) test, a modified version of the Dickey-Fuller test, was also applied. In the PP test, the augmentation term is designed to account for certain kinds of heteroskedasticity and serial correlation in the error term. Based on equations 4.1 to 4.2, possible tests are:

(i) equation 4.1

1. $H_0: \alpha^* = 0$

(ii) equation 4.2

2. $H_0: \alpha^* = 0$
3. $H_0: \alpha^* = 0$ and $\delta = 0$

(iii) equation 4.3

4. $\mathrm{H}_0: \alpha^* = 0$
5. $\mathrm{H}_0: \alpha^* = 0$ and $\beta = 0$
6. $\mathrm{H}_0: \alpha^* = 0$ and $\beta = 0$ and $\delta = 0$

Both t- and z-statistics can be used to test (1), (2) and (4). In this analysis the t-statistics have been used. The F-statistic can be used to perform the other remaining tests.

At first glance, it might appear that a unit root test could be accomplished simply by using the ordinary t statistic for $\rho - 1 = 0$. However, this is not so since when $\rho = 1$ the process generating x_t is integrated of order one. This means that x_{t-1} will not satisfy the standard assumptions needed for asymptotic analysis (Davidson and Mackinnon 1993). Consequently, the t statistic does not have the N(0,1) distribution assymptotically. The SHAZAM package, used to compute the unit root tests, prints the appropriate critical values and these have been used in the study. The results of the tests are reported in Appendix A. Based on the ADF test, the DGP of yield, GDP and output appear to be pure random walk, while expenditures appear to be generated by a mixed process(i.e. random walk with a drift and a trend). On the other hand, the PP test renders the DGP of output to be trend stationary. Both tests agree in regard to the DGP of the other series (i.e., yield, GDP and expenditures).

After testing for the presence on the unit-root in the series' levels, the series were differenced (to induce stationarity) and tested for stationarity. The results of these tests are also reported in Appendix A. Based on the ADF test the first differences of the series appear to be non-stationary. On the other hand, the PP test shows the differenced series to be stationary. Given that the PP test has greater power to reject a false null hypothesis of a unit-root (Enders 1995, p. 242), it was concluded that the first differences of all the series are stationary and that all the series are I(1) (i.e., integrated of order 1).

4.4 Cointegration Tests

The concept of cointegration was first introduced by Granger (1981). It gained popularity after the publication of what Davidson and Mackinnon (1993, p.716) refer to as 'the best-known paper' by Engel and Granger (1987). The idea of cointegration is typically based on long-run equilibrium relationships between variables as suggested by economic theory. Economic theory suggests that although the variables may drift away from equilibrium for a while, economic forces may be expected to act so as to restore equilibrium. Familiar examples of the long-run relationships include short- and long-term interest rates, the quantity theory of money, the Fisher effect, the permanent income hypothesis, and the purchasing power parity. If there is a linear combination of integrated series that is stationary, such variables are said to be cointegrated (Davidson and Mackinnon 1993). The concept of cointegration means that there is an equilibrium relationship among a set of non-stationary variables. This implies that the stochastic trends of these variables are linked and that the variables cannot move independently of each other (Enders 1995). It can therefore be inferred that if two or more variables are cointegrated, they must obey an equilibrium relationship in the long-run.

According to Engel and Granger (1987, p. 253), cointegration can be formerly defined as follows:

The components of the vector x_t are said to be cointegrated of order d, b, denoted $x_t \sim CI(d,b)$, if (i) all components of x_t are I(d); (ii) there exits a vector $\alpha(\neq 0)$ so that $z_t = \alpha' x_t \sim I(d-b)$, b>0. The vector α is called the cointegrating vector.

Given that economic series are mostly I(1), we can concentrate on the case where d=1 and b=1. In this case cointegration would mean that if the components of x_t were all I(1), then the equilibrium error would be I(0), and z_t will rarely drift far from zero if its mean is zero, and equilibrium will occasionally occur, at least to a close approximation. If on the other hand z_t was to drift arbitrarily from zero, then the concept of equilibrium and thus cointegration would be violated (Engel and Granger 1987). Equilibrium in an econometric sense implies a long-run relationship among non-stationary variables.

Cointegration does not require that the long-run (i.e. equilibrium) relationship be generated by market forces or the behavioural rules of individuals. In the Engel and Granger (1987) use of the term, the equilibrium relationship may be causal, behavioural or simply a reduced-form relationship among similarly trending variables. A principal feature of cointegrated variables is that their time paths are influenced by the extent of any deviation from long-run equilibrium. From Engel and Granger's definition above, if x_t has n components, there my be as many as n-1 linearly independent cointegrating vectors. Clearly, if x_t contains only two variables, there can be at most one independent cointegrating vector. The number of cointegrating vectors is called the cointegrating rank of x_t.

From the definition of cointegration above, it follows that the null hypothesis of no cointegration against the alternative of cointegration can be tested based on either the residuals of the cointegrating regression or on the number of cointegrating vectors in the system (cointegrating rank). The popular tests for the former approach are the Augmented Dickey-Fuller (ADF) and the Phillip-Perron (PP) tests, and the Johansen test is used for the latter approach. The Johansen test is considered the most efficient test compared to the residual based tests. However in the two variable case, where there can only be one cointergrating vector, the Johansen test collapses into the residual test. Therefore, in this analysis the residual based tests, namely, the ADF and PP tests, have been employed.

These tests have been recommended in the literature because they account for serial correlation and heteroskedasticity in the error terms of the test regression, an element which is missing in other tests such as the Durbin Watson test (CRDW) and the Dickey-Fuller test (DF). However, in a small-scale study of the properties of different cointegration tests, Engel and Granger (1987) show that when the data generating process of the disturbances of the cointegrating equation is an AR(1) process, the CRDW has higher power of detecting cointegration between series than other tests including the ADF and PP tests. Nevertheless, they discourage its use because the critical values of the test are sensitive to the particular parameters of the data generating process of the disturbances of the cointegrating regression. Since the actual data generating process of the residuals of the cointegrating regression is not known, the CRDW test is used to check the consistency of the ADF and PP tests.

The residual based testing procedure was suggested by Engel and Granger (1987). Three steps are involved in the testing procedure. The first step is to pretest the variables for their order of integration. Second, if integrated of the same order, the long-run equilibrium relationship is estimated and residuals saved. Finally, the saved residuals are tested for stationarity using the augmented Dickey-Fuller test statistic based on the equation 4.5. In this equation, the hypothesis that $\alpha^* = 0$ is tested. If stationary the null hypothesis of no cointegration is rejected, and this means that the series are cointegrated of order (1,1).

$$\Delta \hat{\varepsilon}_t = \alpha^* \hat{\varepsilon}_{t-1} + \text{Augmented terms} + \mu_t \tag{4.5}$$

where the augmentation terms are necessary to ensure that the above regression has residuals that appear to be white noise (Mackinnon 1991).

Distributions of residual-based cointegration test statistics are not the same as those of ordinary unit root test statistics. This is due to the fact that the $\{\hat{\varepsilon}_t\}$ sequence is generated from a regression equation and the actual error ε_t is not known, because the elements of the cointegrating parameter are not known. Engel and Yoo (1987) provide appropriate tables of critical values. However, the tables are only for 50, 100 and 200 observations. Davidson and Mackinnon (1993) also provide tables for asymptotic critical values. Since in both tables there are no appropriate critical values for less than 50 observations, as it is the case in this study, Davidson and Mackinnon's tables have been used.

The Phillips-Perron test is also used to test for stationarity in the residuals. As stated in section 4.3, the ADF and PP tests are similar except that the augmentation term in the PP is designed to account for certain kinds of heteroskedasticity and serial correlation in the error term.

The third test used in the study is the CRDW. The CRWD test statistic is computed using equation 4.6.

$$CRDW = \sum\left(\hat{\mu}_t - \hat{\mu}_{t-1}\right)^2 / \sum_{t-1}^{T} \hat{\mu}_t^2 \tag{4.6}$$

The null hypothesis being tested is of a single root. i.e., μ_t is a random walk. To do the test, after running the cointegrating regression, the Durbin Watson (DW) statistic is tested to see if the residuals appear to be stationary. If they are stationary the DW will approach zero, and thus the test rejects non-cointegration if DW is too big. In conducting the tests all variables are considered as regressands to avoid sample errors which can lead to cointegration not being determined despite its presence. However, if cointegration is found in at least one case, the conclusion should be that there is enough evidence to support cointegration. The results of these tests are reported in table 4.1.

Table 4.1: Cointegration test results

cointegrating Regression	ADF	PP	C-Value	CRDW	C-Val.
1. LEXP/LOUT	-2.328	-2.285	-3.5	0.169	0.89
2. LOUT/LEXP	-3.766*	-4.418**	-3.5	1.577	0.72
3. LEXP/LGDP	-1.779	-1.797	-3.5	0.169	0.89
4. LGDP/LEXP	-2.709	-2.771	-3.04	0.94	0.72
5. LEXP/LY	-1.808	-1.832	-3.5	0.169	0.89
6. LY/LEXP	-2.744	-2.833	-3.04	1.041	0.89

* and **=significant at 10 and 5 percent level respectively. LEXP=log of public agricultural research expenditures, LOUT=log of agricultural output, LGDP=log of agricultural contribution to GDP and LY=log of yield. C-val.=critical value. The critical values for the CRDW test are the 5 per cent critical values for 50 observations extracted from Banerjee, Galbraith and Hendry, 1993 p.209. Critical values for the ADF and PP tests are asymptotical critical values at 10 per cent level printed by SHAZAM.

Based on all the tests, when expenditure is used as a regressand, the null of non-cointegration cannot be rejected. However, when expenditure is used as an explanatory variable, different conclusions are reached. When output is used as a regressand, all the three tests agree and the null of non-cointegration is rejected at the 10 and 5 per cent based on the ADF and PP tests respectively, and 5 per cent based on the CRDW test. When GDP is used as a regressand, both the ADF and PP tests agree and the null of non-cointegration cannot be rejected at the 10 per cent level. However, with the CRDW test the null is rejected at the 5 per cent level. The same result applies to the case when yield is used as a regressand.

The conflicting conclusions between the three tests are probably due to their weakness in detecting cointegration among the series. As Banerjee et al.(1993) observed, the power of these tests to discriminate between unit roots and borderline-stationery processes is weak and the small sample properties are poor. Also, because the series employed in the study are short, this might cause the power of the tests to reject the null to be low and consequently, the tests tend to accept the null even when it is false. Based on these weaknesses and the results it was concluded that cointegration existed between expenditure and output, expenditure and GDP and expenditure and yield. This conclusion is a tentative one because of the above mentioned weaknesses.

One of the major benefits of cointegration is that it allows a single formulation that combines in one model the short-run dynamics and the long-run relationship between the variables at the same time. This formulation is known as the Error Correction Model (ECM) framework. If the two variables are cointegrated, one of the 'speed of adjustment' coefficients (see section 4.5) must be statistically significant (Enders 1995). Therefore, the presence of cointegration among the series is further tested in the ECM framework in the following sections.

4.5 Error Correction Model Framework

The history of the ECM dates back to the late 1970s. It was used by authors such as Davidson, Handry, Srba and Yeo (1978) for the analysis of the consumption function. In 1987, Engel and Granger showed that the cointegrating regression and the ECM had a one-to-one correspondence, since if two variables are cointegrated, their short-run dynamics can be written with an ECM representation. This is called the 'Granger Representation Theorem'.

Given a two variable case, the Granger Representation Theorem can be demonstrated as follows. Let $\{ y_t \}$ and $\{ x_t \}$ be time series variables which are CI(1,1). The variables have the error-correction form:

$$\Delta x_t = \delta_1 + \alpha_1\left(x_{t-\rho} - \beta y_{t-\rho}\right) + \sum_{i=1}^{\rho-1} \gamma_{11}(i)\Delta x_{t-i} + \sum_{i=1}^{\rho-1} \gamma_{12}(i)\Delta y_{t-i} + \mu_{xt} \quad \text{(4.7), and}$$

$$\Delta y_t = \delta_2 + \alpha_2\left(x_{t-\rho} - \beta y_{t-\rho}\right) + \sum_{i=1}^{\rho-1} \gamma_{21}(i)\Delta x_{t-i} + \sum_{i=1}^{\rho-1} \gamma_{22}(i)\Delta y_{t-i} + \mu_{yt} \quad \text{(4.8).}$$

where $\left(x_{t-\rho} - \beta y_{t-\rho}\right)$ = the error-correction term

β = the cointegrating parameter

μ_{xt} and μ_{yt} = white-noise disturbances (which may be correlated with each other)

and α_1, α_2, δ_1, δ_2, $\gamma_{11}(i)$, $\gamma_{12}(i)$, $\gamma_{21}(i)$, $\gamma_{22}(i)$ are all parameters. α_1 and α_2 are known as speed of adjustment coefficients (Enders 1995).

Engel and Granger (1987) proposed a technique for estimating equations 4.7 and 4.8 called 'The Engel-Granger two step estimator'. To circumvent the cross-equation restrictions involved in the direct estimation of these two equations, the Engel-Granger two step technique uses the value of the residual $\hat{v}_{t-p}$ to estimate the deviation from long-run equilibrium in period (t-p). Thus, step one of the estimation technique comprises the estimation of the cointegrating regression of equation 4.9.

$$x_t = A + \beta y_t + \mu_t \qquad (4.9)$$

and saving the residuals. These residuals are then used as an instrument for the expression $\{ x_{t-\rho} - \beta y_{t-\rho} \}$ in 4.7 and 4.8. Thus, using the saved residuals from estimating the long-run equilibrium relationship (step one), the error-correction model is estimated as:

$$\Delta x_t = \delta_1 + \alpha_1\left(\hat{v}_{t-p}\right) + \sum_{i=1}^{\rho-1}\gamma_{11}(i)\Delta x_{t-i} + \sum_{i=1}^{\rho-1}\gamma_{12}(i)\Delta y_{t-i} + \mu_{xt} \qquad (4.10), \text{ and}$$

$$\Delta y_t = \delta_2 + \alpha_2\left(\hat{v}_{t-\rho}\right) + \sum_{i=1}^{\rho-1}\gamma_{21}(i)\Delta x_{t-i} + \sum_{i=1}^{\rho-1}\gamma_{22}(i)\Delta y_{t-i} + \mu_{yt} \qquad (4.11).$$

Other than the error term $\hat{v}_{t-p}$, equations 4.10 and 4.11 constitute a Vector Autoregressive Model (VAR) in first differences. This *near* VAR (as referred to by Enders 1995) is called a restricted VAR in differences and can be estimated by OLS since the regressors are the same in both equations. This comprises the second step of Engel-Granger estimation technique. However, before 4.10 and 4.11 can be estimated, it is important to know the appropriate lag length of the model. The following section deals with lag tests.

4.6 Lag Length Tests

It is important to choose an appropriate lag length of a VAR/ECM before estimation can be done, since choosing ρ (order of the model) unnecessarily large will reduce the forecast precision of the corresponding VAR(ρ)/ECM(ρ) model and thus affect causality tests. Parametric (based on statistical tests) and non-parametric tests can be done to test for the appropriate order of the VAR/ECM model. However, Lutkepohl (1993) demonstrates that the statistical test approach is not completely satisfactory if a model is desired for a specific purpose, like forecasting. Even if the objective is to determine the exact order of the data generating process of the variables, as it is the case in this analysis, the parametric test approach is still not satisfactory. This is because the parametric tests approach has a positive probability of choosing an incorrect order even if the sample size (time series length) is large. Hence non-parametric tests have been employed in this analysis.

The Akaike Information Criterion (AIC) and the Swartz Criterion (SC) statistics have been predominantly used in the literature to test for the order of VAR/ECM models. The two approaches have also been used in this analysis. These tests have been found to be consistent estimators of the appropriate order of the VAR/ECM models. The AIC will asymptotically choose the correct order almost with probability one if the underlying multiple time series has a high dimension of K (the number of regressors). On the other hand, the SC is considered strongly consistent for any dimension of K (Geweke and Meese 1981, Lutkepohl 1993). However, AIC has been found to have better small sample properties than the latter and thus may produce superior forecast results in both small sample and large sample cases even though it may not estimate the orders correctly (Lutkepohl 1993).

Based on the two tests, the optimal lag length is determined by minimising the following functions in equations 4.12 and 4.13

$$AIC = \left(RSS + 2K\sigma^2\right)/T \tag{4.12}$$

$$SC = \left(RSS + K\log T\sigma^2\right)/T \tag{4.13}$$

where K is the number of regressors and T is the number of observations. Lag length test results are reported in Appendix B, Table B. From Table B the lag lengths used in equations 1, 3 and 5 (in Table B) are those that minimised both the AIC and the SC. The lag lengths used in other equations were used to maintain the symmetry of the ECM. This was done because even with the appropriate lag lengths (i.e., those minimising the AIC and the SC), the estimates in the three equations were insignificant.

After determining the appropriate order of the VAR/ECM model, the correct model is specified and estimated. From the estimated model, causality tests can be undertaken. The following section discusses causality tests.

4.7 Causality Tests

Cointegration says nothing about the direction of the causal relationship between the variables, but if two variables are found to be cointegrated, it follows that there must be Granger causality in at least one direction. Causality tests are based on the test proposed by Granger (1981). The test hinges on the idea that random variable x is causally prior to random variable y if the past history of x improves significantly our ability to predict series y compared with our ability to predict series y using all relevant information apart from 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 a bivariate case Granger causality can be demonstrated using equation 4.14 and 4.15.

$$\Delta x_t = \delta_1 + \sum_{i=1}^{\rho-1} \gamma_{11}(i)\Delta x_{t-i} + \sum_{i=1}^{\rho-1} \gamma_{12}(i)\Delta y_{t-i} + \mu_{xt} \tag{4.14}$$

$$\Delta y_t = \delta_2 + \sum_{i=1}^{\rho-1} \gamma_{21}(i)\Delta x_{t-i} + \sum_{i=1}^{\rho-1} \gamma_{22}(i)\Delta y_{t-i} + \mu_{yt} \tag{4.15}$$

Using the definition of causality given above, y causes x if some $\gamma_{12}(i)$ is not zero in equation 4.14. In the same way x causes y if some $\gamma_{21}(i)$ is not zero in equation 4.15. If both of these events occur, a feedback relationship is said to exist between the two variables.

Using Monte Carlo methods, Geweke, Meese, and Dent (1983) found that the Wald test outperforms other tests in detecting the presence or absence of causality. Hence, the Wald test has been used in this analysis to test for causality. The Wald test statistic is calculated by estimating the above expressions in both unconstrained and constrained forms (full and reduced models):

$$\lambda_W = \frac{SSE_R - SSE_U}{\hat{\sigma}^2}$$

where SSE_R *and* SSE_U = residual sum squares of the reduced and full models, respectively, and

$\hat{\sigma}^2$ = estimated variance from unrestricted model.

λ_W follows a χ_J^2 distribution where J is the number of restrictions.

In the ECM framework an additional condition is required for Granger causality. Using equations 4.10 and 4.11 Granger causality in the ECM framework can be explained as follows:

The variable y Granger-causes the variable x if some $\gamma_{12}(i) \neq 0$ and $\alpha_1 \neq 0$, and x Granger-causes y if some $\gamma_{21}(i) \neq 0$ and $\alpha_2 \neq 0$. Feedback causality between x and y occurs when some of $\gamma_{12}(i) \neq 0$, $\gamma_{21}(i) \neq 0$ and, $\alpha_1 \neq 0$ and / or $\alpha_2 \neq 0$ (Enders 1995, p. 371-372). The-t test can be used to test the statistical significance of α_1 and α_2 and the F-test to test the restrictions $\gamma_{12}(i) = 0$ or $\gamma_{21}(i) = 0$. The results of Granger causality are reported and discussed in the following chapter.

5. Empirical Results

5.1 Introduction

The empirical findings and interpretations are presented in this chapter. The findings reported in this chapter follow from data pre-testing results reported in Chapter 4 (i.e., unit root and cointegration test results). Therefore, this chapter is mainly on causality tests. The findings reported establish whether causality holds between research and agricultural output in Lesotho, where research is measured by public agricultural research expenditures and output by (a) an index of total agricultural output, (b) a partial factor productivity index (yield index) and (c) a GDP index representing the amount of GDP contributed by agriculture. Section 5.2 presents the estimated ECM models and the interpretation of the estimates of long-run cointegrating relationships. Section 5.3 provides a brief account of the nature of agricultural research in Lesotho and some of the factors which influence farmers' adoption of new technologies. In section 5.4 causality tests are presented and interpreted. Finally, concluding remarks are provided in section 5.5.

5.2 ECM Models Estimated

Based on the lag tests performed in Chapter 4, the appropriate lag length for the ECM models of output and expenditure, and yield and expenditure were found to be 8 and 7 years respectively. This result is in keeping with the theoretical literature which states that the peak effect of research and development on agricultural output does not occur until six or seven years (Schmmelpfenning and Thirtle 1994). The appropriate lag length for the ECM model for GDP and expenditure was found to be 7 years. This result is logical from the latter given that GDP in this case represent the amount of GDP contributed by agriculture. However, given the shortness of the series employed in this study, it is possible that the appropriate lag lengths could be longer than the ones recommended by the tests. This matter is further explored in section 5.3.

Based on the lag length results, the following ECM models were estimated:

(5.1) output and expenditure

$$\Delta lx_{1t} = \delta_1 + \alpha_1\left(\hat{v}_{t-8}\right) + \sum_{i=1}^{7}\gamma_{11}(i)\Delta lx_{1_{t-i}}t + \sum_{i=1}^{7}\gamma_{12}(i)\Delta lx_{2_{t-i}} + \mu_{1xt}$$

$$\Delta lx_{2t} = \delta_2 + \alpha_2\left(\hat{v}_{t-8}\right) + \sum_{i=1}^{7}\gamma_{21}(i)\Delta lx_{1_{t-i}}t + \sum_{i=1}^{7}\gamma_{22}(i)\Delta lx_{2_{t-i}} + \mu_{2xt}$$

where,

Δlx_{1t} = change in log of output, and
$\Delta l\mathrm{x}_{2\mathrm{t}}$ = change in log of expenditure

(5.2) yield and expenditure

$$\Delta lx_{1t} = \delta_1 + \alpha_1\left(\hat{v}_{t-7}\right) + \sum_{i=1}^{6}\gamma_{11}(i)\Delta lx_{1_{t-i}}t + \sum_{i=1}^{6}\gamma_{12}(i)\Delta lx_{2_{t-i}} + \mu_{1xt}$$

$$\Delta lx_{2t} = \delta_2 + \alpha_2\left(\hat{v}_{t-7}\right) + \sum_{i=1}^{6}\gamma_{21}(i)\Delta lx_{1_{t-i}}t + \sum_{i=1}^{6}\gamma_{22}(i)\Delta lx_{2_{t-i}} + \mu_{2xt}$$

where Δlx_{1t} is change in log of yield and $\Delta \mathrm{lx}_{2\mathrm{t}}$ is as in 5.1

(5.3) GDP and expenditure

$$\Delta lx_{1t} = \delta_1 + \alpha_1\left(\hat{v}_{t-7}\right) + \sum_{i=1}^{6}\gamma_{11}(i)\Delta lx_{1_{t-i}}t + \sum_{i=1}^{6}\gamma_{12}(i)\Delta lx_{2_{t-i}} + \mu_{1xt}$$

$$\Delta lx_{2t} = \delta_2 + \alpha_2\left(\hat{v}_{t-7}\right) + \sum_{i=1}^{6}\gamma_{21}(i)\Delta lx_{1_{t-i}}t + \sum_{i=1}^{6}\gamma_{22}(i)\Delta lx_{2_{t-i}} + \mu_{2xt}$$

where Δlx_{1t} is change in log of GDP and $\Delta \mathrm{lx}_{2\mathrm{t}}$ is as in 5.1 and 5.2 .

The long-run cointegrating relationships of these models are given by:

model 5.1

$$lx_t = \alpha + \beta ly_t + \varepsilon_t \tag{5.4}$$

where lx_t and ly_t are log of output and log of expenditures respectively.

model 5.2

$$lx_t^* = \alpha + \beta ly_t + \varepsilon_t \tag{5.5}$$

where lx_t^* and ly_t are log of yield and log of expenditures respectively.

model 5.3

$$lx_t^{**} = \alpha + \beta ly_t + \varepsilon_t \tag{5.6}$$

where lx_t^{**} and ly_t are log of GDP and log of expenditures respectively.

Because the variables in equations 5.4 to 5.6 are cointegrated, their estimation is superconsistent (Davidson and Mackinnon 1993). Table 5.1 below reports estimates of the long-run cointegrating relationships.

Table 5.1: Results of cointegrating regressions

cointegrating regression	α	β
5.4	4.633	-1.579
5.5	-0.074	-0.404
5.6	0.048	4.666

Since the long-run cointegrating relationships are in the log-linear form, the estimates of β are interpreted as long-run elasticities of production or output.

The estimate of β show the nature of co-movement between agricultural research and agricultural output in the long-run. The sign of β in 5.4 and 5.5 is not as expected. According to economic theory, the long-run output elasticity would be expected to be positive suggesting that a one percent increase in research expenditures today will result in a positive percentage change in agricultural output in the long-run. This poor result may be manifested in the poor quality of the data employed in this study, or in the nature of agricultural research undertaken in Lesotho, and/or in factors affecting adoption of new technologies by farmers in Lesotho. This is the subject of the following section.

5.3 Agricultural Research in Lesotho and Factors which Influence Adoption of New Technologies

In Lesotho there are more traditional than commercial or modern farmers whose farming decisions are influenced by more factors that those of modern farmers. It is therefore essential for research institutes in Lesotho to consider all relevant factors to ensure at least a modest degree of success in agricultural research done for traditional farmers. To account for these factors, the Lesotho Agricultural Research Division (ARD) (which undertakes most of Lesotho's agricultural research) decided to embark upon an 'applied agricultural systems research' strategy. Under this system, 'on-farm adaptive research' is the crucial principle and the farmers are expected to play a significant role in decisions relating to the adoption of new technologies. Most of the research undertaken by the division is agronomic. A number of steps are involved under this system:

- The Lesotho Research Division identifies a relevant group of farmers to be involved in on-farm trials. The identification is based on factors such as the natural environment, socio-economic circumstances and nature of technology proposed.
- The research is then organised bearing in mind the constraints and opportunities of the target group of farmers .
- A representative site on which to do research is selected. The useful research findings from this site may be later diffused by extension methods to the rest of the homogeneous group or area.
- When the site has been selected, the individual farmers on whose farms research would take place are selected.
- If the technology is verified as appropriate by convincing success on several of the chosen sites, it is recommended and extended to all other farmers of the homogeneous group (ARD 1991).

However, a number of constraints prevent the smooth execution of all the above steps. The ARD lacks suitable research staff (ARD 1991) which sometimes handicaps the proper on-farm trials. Also, there is an acute shortage of extension staff. Because of this problem not all the farmers in the homogeneous group are informed about a new technology after the on-farm trials have been successful. Also, dissemination of information about improved technologies is handicapped by the absence of newsletters or farmers' bulletins. All these result in a long lag between the success of the on-farm trial and adoption of new technologies.

The ARD has also observed that there is inadequate agricultural research education among the farmers, which in most cases affects the communication between the research staff and the farmers, thus, resulting in wrong applications of recommended technologies. Other than lack of adequate education, Basotho (Lesotho people) farmers' efforts are mainly handicapped by lack of agricultural resources. These are mainly manifested in the form of credit availability. Most Basotho farmers are poor and thus can barely afford to purchase expensive inputs, required for improved technologies, without credit facilities. Consequently, a number of farmers end up with wrong mixtures for recommended technologies. These problems explain the negative coefficients of the early lags of research variable in the three models (see Appendix D). Although some coefficients are not significant, from the explanation above it can be deduced that the introduction of a new technology is highly likely to result in a negative impact on total factor productivity in the early years of the introduction of the technology.

Agriculture in Lesotho is mainly rainfed. Some technologies require good rains. If drought breaks in a period when good rains were expected, agricultural production falls, thus rendering technologies applied in that year inefficient. This kind of a problem has been experienced in a number of periods in Lesotho. For example, in 1991 the country was hit by a major drought and many farmers incurred huge losses in terms of poor yields. However, these structural changes could not be captured in the study because of lack of information on the exact drought periods in Lesotho.

Another major problem concerns the inadequacy of socio-economic inputs into the programs of ARD. Although, as stated in the steps above, one of the criteria used in selecting the target group is the socio-economic structure of the group, the ARD has been criticised for ignoring the socio-economic characteristics of farmers in recommending technologies. For example, a high yielding 'short-stock' wheat variety was introduced in the mountains region in 1989. However, because people in the mountains use wheat stocks for roofing purposes, the technology was not widely adopted and the money invested in it became a waste.

Because of all the above mentioned reasons it is possible that research in Lesotho can yield negative results in the early years of a new technology. It is also possible that these negative results can be so big that they outweigh positive results which occur in the later years of the introduction of a new technology, and hence why the long-run relationship between agricultural research and agricultural output appears to be negative.

The residuals obtained from the cointegrating regressions 5.4 to 5.6 were used in estimating the ECM models 5.1, 5.2 and 5.3. The coefficient estimates of these models are reported in Appendix C. These estimates have been reported mainly for reference purposes and thus, are only lightly discussed. The results show that agricultural research have a negative impact on the agricultural output in the early years of research. However, in the later years of research a possitive impact is observed on agricultural output.

Since causality tests are crucial in this analysis, Granger causality tests and a comprehensive interpretation of the tests is provided in the following section.

5.4 Granger Causality Tests

The procedure described in Chapter 4 was followed in calculating causality tests and the results are reported in tables 5.2 and 5.3 below. Column 1 in tables 5.2 and 5.3 give the direction of causality (i.e., expenditure $\rightarrow$ output indicates that we are testing if expenditure leads output). Column 2 and 4 contain the statistics for the null hypothesis of no causality. Columns 3 and 5 have information about the percentage at which the null hypothesis is rejected.

From table 5.2 the hypothesis that research does not cause output was rejected in all cases. The null of no causality was strongly rejected when partial productivity (yield) was used as a measure of agricultural output. This shows that 'the productivity variable is, a priori, the most appealing measure of agricultural output if one is looking for support of the science-based view of technological change' (Pardey and Graig 1989, p. 16). The tests provide support for causality running from research to agricultural output regardless of the measure used for agricultural output. This result conforms to economic theory which states that agricultural research influences agricultural output, or productivity of production factors.

Table 5.2: Granger test results, null hypothesis: research does not cause output

λ_W for the null: $\sum_{i=1}^{7} \gamma_{12}(i) = 0,$ $\sum_{i=1}^{6} \gamma_{12}(i) = 0$ $\quad$ t_{cal} for the null: $\alpha_i = 0$, i=1,2

Direction of causality	λ_W	p-value	t_{cal}	p-value
expenditure → output	12.23	0.09*	-1.95	0.04**
expenditure → yield	17.68	0.007***	-1.91	0.05**
expenditure → GDP	32.42	0.00***	-2.08	0.04**

λ_W is the Wald Chi-square statistic, t_{cal} is the t statistic. *, **, *** mean significant at 10, 5 and 1 percent levels respectively.

Table 5.3: Granger test results, null hypothesis: output does not cause research

λ_W for the null: $\sum_{i=1}^{7} \gamma_{21}(i) = 0, \quad \sum_{i=1}^{6} \gamma_{21}(i) = 0$ $\qquad t_{cak}$ for the null: $\alpha_i = 0$, i=1,2

Direction of causality	λ_W	p-value	t_{cal}	p-value
output → expenditure	2.59	0.92	0.07	0.47
yield → expenditure	1.09	0.98	-0.27	0.39
GDP → expenditure	1.77	0.94	0.34	0.37

λ_W is the Wald Chi-square statistic, t_{cal} is the t statistic.

Causality from output to research was strongly rejected regardless of the measurement of agricultural output. This result is not surprising given that in Lesotho research is mainly funded by donor agencies. The main objective of these agencies in allocating funds to agriculture is to develop its poor performance and make it more efficient. Therefore, the allocation of funds in this case is not driven by the good performance of the agricultural sector as it would be expected in the case of a feedback relationship between research and output. Consequently, from the results it can be concluded that agricultural research in Lesotho is not demand driven.

The error correction terms (i.e., α_1 and α_2) in the Granger causality tests have an important interpretation. They have the interpretation of speed of adjustment parameters. They measure the amount by which the dependent variable changes as a response to a deviation in the long-run equilibrium. Therefore, they have important implications for the short-run dynamics of the system in each model. For credible results the absolute values of these parameters must not be too large, at least one of them should be significantly different from zero (cointegration condition) and one should be positive and the other negative to necessitate direct convergence to equilibrium (Enders 1995). The larger α_1 is (for example in the output/expenditure model), the greater the response of output to the previous period's deviation from long-run equilibrium. On the other hand, very small values of α_1 imply that output is unresponsive to last period's equilibrium error (Enders 1995). Table 5.4 reports parameters of speed of adjustment coefficients for the explanatory variables in models 5.1, 5.2 and 5.3.

In model 5.1 (output/expenditure) α_1 is -1.655 and α_2 is 0.069. The absolute value of α_1 is too big. However, the signs of the two parameters necessitate direct convergence toward long-run equilibrium. The large negative value of α_1 implies that a deviation in the long-run equilibrium results in a sharp decrease in agricultural output. On the other hand the small positive value of α_2 implies that a deviation in the long-run equilibrium results in a minimal increase in public agricultural research expenditures. The point estimates imply that in the presence of a one-unit deviation

Table 5.4: Parameters of speed of adjustment coefficients

ECM model	α_1	T-ratio	α_2	T-ratio
5.1	-1.655	-1.953**	0.069	0.065
5.2	-0.695	-1.915**	-0.064	-0.267
5.3	-0.684	-2.084**	0.136	0.338

** means significant at 5 percent level

from long-run equilibrium in period t-8, total agricultural output falls by 1.655 units and public agricultural research expenditures increase by 0.069 units. Both these measures in period t-7 act to eliminate the possible discrepancy from long-run equilibrium present in period t-8. The magnitude of α_1 is very high relative to that of α_2 and the coefficient of α_2 is highly insignificant . This result is consistent with causality tests which showed that public agricultural research expenditures in Lesotho are independent of agricultural output, but agricultural output responds to changes in the public agricultural research expenditures. The high value of α_1 also suggests that total agricultural output in Lesotho is highly sensitive to equilibrium error.

In the case of yield and expenditure (equation 5.2), the results are more plausible than in the latter case in terms of the magnitudes of the alphas. However, in this case the solution is not convergent towards long-run equilibrium because both alphas have negative signs. From table 5.4, a one-unit deviation from long-run equilibrium in period t-7 leads to a 0.695 unit fall in yield and 0.064 unit fall in expenditures. Thus, from the result there is no tendency for the solution to return to equilibrium. This could imply that the long-run relationship between expenditures and yield is weak and unstable. The instability of the relationship may be because the underlying structure has changed over the sample period or because of the imperfect measurement of output and/or research.

There have been some structural changes over the sample period, like periods of drought which are believed to have had a significant impact on agricultural productivity and thus, on the results obtained here. However, because of lack of enough proof, these structural changes were not included in the model for estimation purposes. Also, the measurement of productivity (yield) could be imprecise because not all the major agricultural inputs were included in its measure. Moreover, the measurement of agricultural research expenditures may not be proper because of the high level of aggregation assumed in its measure.

The results from the GDP/expenditure model are more plausible than the output or yield models in terms of the magnitudes and signs of the alphas. The signs of the alphas are more plausible since they necessitate direct convergence to equilibrium. Like in cases of output/expenditure and yield/expenditure, deviation from long-run equilibrium leads to a fall in GDP, although the fall is not as large as in the former two cases. i.e., α_1 is -0.684 implying that a one-unit deviation from the long-run equilibrium in period t-7 results in 0.684 units fall in GDP and 0.136 units increase in research expenditures. However, like in the former two cases, only α_1 is statistically significant. This result is also consistent with causality tests which showed that the allocation of public research funds to the agricultural sector in Lesotho is independent of the importance of the sector, but the importance of the agricultural sector is influenced by events in the allocation of public research funds.

5.5 Concluding Remarks

The lag tests which were undertaken in Chapter 4 showed that the minimum amount of time it takes for agricultural research to have a significant impact on agricultural output/productivity is seven years. This lag conforms to economic theory which says that the minimum time it takes for research to have a significant impact on output/productivity is 6 years. However, given the shortness of the series employed in this analysis and the problems inherent in agricultural production in Lesotho mentioned above, it is possible that the lag could be longer than the 7 or 8 years recommended by this study. Also, from Chapter 4, it was found that expenditure and each of the three measures of output are cointegrated. This implies that the relationship between public agricultural research expenditures and agricultural output measures is stable. The major inference from this chapter is that public agricultural research expenditures cause agricultural output. In the next chapter the major conclusions drawn from the study and recommended policy implications are presented.

6. Conclusions and Policy Implications

6.1 Introduction

This study has examined the causal relationship between public agricultural research expenditures and agricultural output. The objective was to address the following questions:

- whether public agricultural research expenditures lead agricultural output in Lesotho and/or whether it is the other way round, and whether the relationship is a feedback one,
- whether the relationship between public agricultural research expenditures and agricultural output is stable overtime,
- how much time it takes for agricultural research in Lesotho to have significant impact on agricultural output, and
- whether the allocation of public agricultural research funds in Lesotho is influenced by the importance of the agricultural sector.

The first step in addressing the above posed questions was to pre-whiten the data through unit-root tests. Then cointegration tests, between research expenditure and each of the agricultural output variables, were performed. With the presence of cointegration between the expenditure and each of the output variables, the ECM model in each case was formulated and tested for appropriate lag length using the AIC and SC tests. Based on the lag length tests, the suitable ECM model for each pair (i.e.,research expenditure and each of the output variables) was formulated and estimated. Granger causality tests were then performed on the estimates of each model. The following section addresses the major findings of the study, followed by derived policy implications in section 6.3. Section 6.4 discusses the limitations of the study. Last, but not least, suggestions for further research are provided in section 6.5.

6.2 Major Findings of the Study

Accepting that there are difficulties with the quality of the data employed in this study, public agricultural research expenditures and agricultural output were shown to be cointegrated, implying that the relationship between the two is stable. Also, the analysis reveals the unidirectional causality between agricultural research and agricultural output where agricultural output is causally prior to public agricultural research expenditures. This indicates that in the case of Lesotho, the traditional single equation approach to investigating the returns to R&D may be adequate, at least for these data. Furthermore, the analysis shows that the minimum time it takes for agricultural research to have significant impact on agricultural output is 8 years. However, from the point estimates of the ECM models, it is observed that agricultural research has a negative impact on agricultural output in the early years of agricultural research. Also, from the analysis, it can be shown that the allocation of public agricultural research in Lesotho is independent of the importance of the agricultural sector.

6.3 Policy Implications

As indicated in the first chapter, agricultural research in Lesotho is basically project-driven both in terms of funding and programs. This situation has persisted almost since the inception of agricultural research in the Ministry of Agriculture (ISNAR 1989). 'This has led to the low-profile status accorded to agricultural research and to a low level of reckoning in resource allocation matters.' (ISNAR 1989, p.15). The major investments in research for the support of programs and the training of staff come mainly from donor sources. The government's main contribution is in the provision of personnel costs and minimal operating costs 'which do not approach what can be considered reasonable requirements of funding per scientist for productive agricultural research' (ISNAR 1989, p.15). These findings have subjected the government of Lesotho to much of criticism related to under investing in agricultural research and of not creating a healthy working climate for the research staff which is necessary to retain them on the job.

The observed lack of interest by the government of Lesotho in agricultural research may be for a multiplicity of reasons. One possible reason is that the government may not have realised that agricultural research drives agricultural output in Lesotho. From the findings of this study the main policy implication is for the government to increase its financial support for agricultural research since it has been clearly shown, in spite of the poor data employed in this study, that agricultural research is a driving force of growth of the agricultural sector in Lesotho. As long as increased spending on research by the government does not lead to a reduction in overseas sources of research funds, it probably makes sense to recommend an increase. However, given the possible factors which may influence the rate at which farmers adopt new technologies (in Chapter 5), the government should not only concentrate on injecting more funds in agricultural research, it should also concentrate its efforts towards solving problems encountered by farmers in adopting new technologies. The following are suggested areas which the government should also concentrate on when supporting agricultural research in the country:

- more research staff, both technical and extension, should be trained,
- a conducive working climate for research staff should be created to retain them on the job. This could be in the form of improved salaries or benefits,
- farmers should be given or encouraged to have minimal education which will ease communication between them and research staff, mainly extentionists,
- there should be good dissemination of information concerning new technologies and this should be in the form of language that can be easily understood by farmers,

- irrigation facilities should be provided,
- socio-economic factors of farmers should be carefully examined before any technology can be recommended, and most importantly,
- credit facilities affordable by small-holder farmers should be provided and monitored carefully to ensure the success of the scheme.

Credit facilities for farmers already exist in Lesotho, but there have been some complaints that they favour commercial farmers at the expense of traditional farmers, who unfortunately happen to comprise a large percentage of farmers in Lesotho. If the above recommended support could be granted to the agricultural sector, it may shorten the lag between agricultural research and agricultural output.

However, it is difficult based on the available information to press hard on the government to increase funding on agricultural research because as economists would argue, it is the internal rate of return from the marginal Loti (or marginal dollar) invested in agricultural research which will determine how much should be invested in agriculture. Thus, the next step from this analysis would be the calculation of returns from agricultural research. Nevertheless, given that agriculture in Lesotho is the occupation of 85 percent of Basotho people, and that it has always been the government's policy to improve agricultural productivity for food security purposes, it seems consistent to recommend an increase in spending on agricultural research.

6.4 Limitations of the Study

The major limitation of the study is the inadequacy of data. The data series employed in this study may be too short to capture the full impact of agricultural research on agricultural output in Lesotho. The data on agricultural research expenditures are highly aggregated and this could have affected the results. For example, if the data was disaggregated, different deflators could have been used for specific measures and that could have possibly had a different impact on the results. Because of insufficient data, the measure of agricultural productivity is limited.

Also, unconventional inputs could not be accounted for because of insufficient data. Moreover, there are some structural adjustments which took place over the sample period, for example, drought periods, but because of lack of information on the exact periods, these were not accounted for in the study.

Futhermore, there is a possibility that there are some spillover effects which are not captured by the Lesotho Agricultural Research System. These were not accounted for in the study. Additionally, spillover effects from the private sector, although they are believed to be very minimal, were not accounted for in the study. All these defects could have had a significant impact on the results obtained.

6.5 Further Research

The results of causality tests reported in this analysis represent a preliminary step in a study of the returns to public sector research in agriculture in Lesotho. They do not provide detailed information on the lag structure or stability of the relationship between research and output overtime, neither do they provide information on returns from agricultural research. To complement this study it is recommended that the above mentioned gaps be filled.

Because of the shortness of the series employed in this study, the causality test results obtained may be considered tentative. However, the results do provide important information concerning the relationship between agricultural research and agricultural output. The results also have important implications for the models and methods which are appropriate for the estimation of structural parameters. It is therefore recommended that the same study be replicated with better data comprising a longer series, a proper measure of TFP, and appropriate measures of public agricultural research expenditures at a disaggregated level. Also, the study should account for unconventional inputs and possible spillover effects not captured by the Lesotho Agricultural Research System.

Alternatively, since the results of this study have already established that research and agricultural output in Lesotho are cointegrated and that agricultural research leads agricultural output, it is recommended that a complementary study which measures returns from agricultural research be performed. There is also a need for a study that can compare and carefully contrast results at different levels of aggregation of the research expenditures and agricultural output variables to detect and measure the importance of social returns to R&D.

Appendix A

Unit-Root Tests

Table A1: Dickey-Fuller tests (series at levels)

Variable name & nlags	no constant (eq. 4.31)	Constant without trend (eq. 4.32)		Constant with trend (eq. 4.33)		
	t-test (1)	t-test(2)	F-test (3)	t-test (4)	F-test(5)	F-test (6)
1. yield						
nlag=0	-1.48	-2.67*	3.62	-2.76	3.87	2.62
nlag=1	-1.25	-2.75*	3.89	-2.77	3.89	2.67
nlag=3	-0.73	-1.98	2.03	-2.01	2.07	1.43
nlag=5	-0.63	-1.94	1.91	-2.06	2.37	1.60
nlag=7	-0.35	-1.31	0.85	-1.55	2.84	1.89
2. output						
nlag=0	-0.39	-3.74*	7.05*	-4.29*	9.34*	6.28*
nlag=1	-0.49	-3.43*	6.01*	-4.09*	8.50*	5.76*
nlag=3	-0.42	-1.86	1.82	-2.51	3.18	2.18
nlag=5	-0.34	-1.48	1.14	-2.54	3.24	2.21
nlag=7	-0.48	-1.29	0.94	-2.66	3.56	2.47
3. GDP						
nlag=0	-0.51	-2.59*	3.45	-2.49	3.23	2.22

nlag=1	-0.55	-2.50	3.25	-2.43	3.03	2.10
nlag=3	-0.14	-1.89	1.80	-1.54	1.78	1.19
nlag=5	-0.15	-2.11	2.24	-1.71	2.13	1.42
nlag=7	0.07	-2.41	2.91	-1.50	3.19	2.13
4. Expenditures						
nlag=0	-7.48*	-5.63*	27.04*	-2.68	15.31*	17.45*
nlag=1	-4.63*	-3.96*	10.43*	-2.09	7.83*	6.9*
nlag=3	-2.92*	-2.71*	4.17*	-1.62	5.46*	4.00
nlag=5	-2.74*	-2.69*	3.64	-2.23*	3.99*	2.66
nlag=7	-2.92*	-2.79*	4.01	-2.72	6.43*	4.38*

critical values for tests 1 to 6 are -1.62, -2.57, 3.78, -3.13, 5.34 and 4.03 respectively. nlag means the number of lags and * means that the null is rejected at 10 percent level.

Table A2: Dickey-Fuller tests (first differences)

Variable name & nlags	no constant (eq. 4.31)	Constant without trend (eq. 4.32)		Constant with trend (eq. 4.33)		
	t-test (1)	t-test(2)	F-test (3)	t-test (4)	F-test(5)	F-test (6)
1. Yield						
nlag=0	-5.58*	-5.51*	15.18*	-5.39*	14.65*	9.77*
nlag=1	-5.23*	-5.15*	13.25*	-5.05*	12.75*	8.50*
nlag=3	-2.25*	-2.20	2.44	-2.13	2.40	1.61
nlag=5	-2.17*	-2.12*	2.25*	-2.13	2.35	1.57
nlag=7	-2.27*	-2.20	2.43	-2.59	3.37	2.26
2. Output						
nlag=0	-6.88*	-6.79*	23.13*	-6.69*	22.45*	14.99*
nlag=1	-6.14*	-6.06*	18.41*	-5.92*	17.70*	11.85*
nlag=3	-3.59*	-3.52*	6.29*	-3.36*	5.92*	4.06*
nlag=5	-2.68*	-2.64*	3.53	-2.52	3.28	2.23
nlag=7	-2.22*	-2.13	2.30	-2.07	2.15	1.45
3. GDP						
nlag=0	-5.77*	-5.68*	16.16*	-5.59*	15.659*	10.45*
nlag=1	-4.33*	-4.29*	9.38*	-4.20*	8.83*	5.98*
nlag=3	-1.82*	-1.77	1.62	-1.62	1.93	1.32
nlag=5	-2.85*	-2.75*	3.80*	-2.92	5.85*	3.90

nlag=7	-1.44	-1.27	0.98	-1.74	1.76	1.29
4. Expenditures						
nlag=0	-3.89*	-4.41*	9.87*	-5.92*	17.92*	12.07*
nlag=1	-2.99*	-3.38*	5.85*	-5.30*	14.76*	9.98*
nlag=3	-2.42*	-2.12	2.91	-2.87	5.00	3.86
nlag=5	-1.52	-1.13	1.09	-2.31	2.95	2.35
nlag=7	-2.29*	-1.57	2.59	-1.96	2.84	2.91

critical values for tests 1 to 6 are -1.62, -2.57, 3.78, -3.13, 5.34 and 4.03 respectively. nlag means number of lags and * means that the null is rejected at 10 percent level.

Table A3: Phillip-Perron tests (series at levels)

Variable name & nlags	no constant (eq. 4.31)	Constant without trend (eq. 4.32)		Constant with trend (eq. 4.33)		
	t-test (1)	t-test(2)	F-test (3)	t-test (4)	F-test(5)	F-test (6)
1. Yield						
nlag=0	-1.49	-2.76*	3.88*	-2.84	4.13	2.79
nlag=1	-1.49	-2.76*	3.88*	-2.84	4.13	2.79
nlag=3	-1.32	-2.64*	3.53	-2.74	3.81	2.57
nlag=5	-1.37	-2.61	3.44	-2.70	3.68	2.50
nlag=7	-1.33	-2.45	2.99*	-2.51	3.09	2.11
2. Output						
nlag=0	-0.44	-3.77*	7.20*	-4.32*	9.49*	6.38*
nlag=1	-0.44	-3.77*	7.20*	-4.32*	9.49*	6.38*
nlag=3	-0.58	-3.64*	6.66*	-4.16*	8.72*	5.88*
nlag=5	-0.62	-3.69*	6.89*	-4.11*	8.41*	5.69*
nlag=7	-0.71	-3.72*	6.99*	-4.05*	7.97*	5.41*
3. GDP						
nlag=0	-0.53	-2.65*	3.63	-2.57	3.42	2.33
nlag=1	-0.53	-2.57	3.62	-2.57	3.42	2.33
nlag=3	-0.58	-2.57	3.39	-2.47	3.17	2.18
nlag=5	-0.58	-2.55	3.35	-2.45	3.13	2.15

nlag=7	-0.64	-2.36	2.84	-2.25	2.58	1.79
4. Expenditures						
nlag=0	-7.95*	-5.96*	30.64*	-2.78	17.40*	19.97*
nlag=1	-7.95*	-5.97*	30.64*	-2.79	17.40*	19.98*
nlag=3	-9.13*	-6.83*	40.72*	-3.09	23.76*	27.64*
nlag=5	-9.18*	-6.89*	41.39*	-3.13	24.73*	28.78*
nlag=7	-10.27*	-7.71*	52.25*	-3.46*	32.40*	38.02*

critical values for tests 1 to 6 are -1.62, -2.57, 3.78, -3.13, 5.34 and 4.03 respectively. nlag means number of lags and * means that the null is rejected at 10 percent level.

Table A4: Phillip-Perron tests (first differences)

Variable name & nlags	no constant (eq. 4.31)	Constant without trend (eq. 4.32)		Constant with trend (eq. 4.33)		
	t-test (1)	t-test(2)	F-test (3)	t-test (4)	F-test(5)	F-test(6)
1. Yield						
nlag=0	-5.59*	-5.52*	15.20*	-5.40*	14.64*	9.77*
nlag=1	-5.59*	-5.52*	15.20	-5.40*	14.64*	9.76*
nlag=3	-5.81*	-5.71*	16.02*	-5.56*	15.15*	10.11*
nlag=5	-5.91*	-5.82*	16.53*	-5.67*	15.57*	10.39*
nlag=7	-6.37*	-6.28*	18.88*	-6.16*	17.79*	11.88*
2. Output						
nlag=0	-6.97*	-6.88*	23.65*	-6.77*	22.88*	15.28*
nlag=1	-6.97*	-6.88*	23.65*	-6.78*	22.88*	15.28*
nlag=3	-7.94*	-7.84*	30.11*	-7.68*	28.46*	19.02*
nlag=5	-8.28*	-8.19*	32.73*	-7.99*	30.54*	20.42*
nlag=7	-9.13*	-9.14*	40.24*	-8.84*	36.82*	24.62*
3. GDP						
nlag=o	-5.77*	-5.69*	16.19*	-5.59*	15.67*	10.46*
nlag=1	-5.77*	-5.69*	16.19*	-5.59*	15.67*	10.46*
nlag=3	-5.88*	-5.80*	16.68*	-5.69*	15.99*	10.68*
nlag=5	-5.92*	-5.83*	16.80*	-5.73*	16.09*	10.75*

nlag=7	-6.20*	-6.08*	18.03*	-5.99*	17.26*	11.54*
4. Expenditures						
nlag=0	-3.87*	-4.41*	9.82*	-5.96*	18.13*	12.22*
nlag=1	-3.87*	-4.41*	9.81*	-5.96*	18.13*	12.22*
nlag=3	-3.87*	-4.41*	9.81*	-6.34*	20.16*	13.66*
nlag=5	-3.89*	-4.44*	10.03*	-6.33*	20.15*	13.64*
nlag=7	-3.93*	-4.49*	10.25*	-6.71*	22.42*	15.22*

critical values for tests 1 to 6 are -1.62, -2.57, 3.78, -3.13, 5.34 and 4.03 respectively. nlag means the number of lags and * means that the null is rejected at 10 percent level.

Appendix B

Lag Length Tests

The cointegrating regressions 1 to 6 were run using SHAZAM and the AIC and the SC were computed based on functions 4.12 and 4.13 respectively. The following table lists the results that were obtained.

Table B1: Results of lag length tests

Model: ECM model

equation	lag	AIC	SC	lag used
1. LOUT/LEXP	1	0.016	0.019	
	2	0.019	0.024	
	3	0.020	0.027	
	4	0.025	0.037	
	5	0.027	0.045	
	6	0.027	0.049	
	7	0.017	0.035	
	8	0.010	0.022*	8
	9	0.012	0.031	
	10	0.013	0.035	
2. LEXP/LOUT	1	0.017	0.021	
	2	0.019	0.025	

	3	0.021	0.027	
	4	0.017	0.026	
	5	0.018	0.030	
	6	0.021	0.038	
	7	0.024	0.047	
	8	0.014	0.031	8
	9	0.004	0.009	
	10	0.001	0.003*	
3. LGDP/LEXP	1	0.047	0.055	
	2	0.043	0.053	
	3	0.051	0.018	
	4	0.058	0.086	
	5	0.058	0.096	
	6	0.036	0.066	
	7	0.019	0.038*	7
	8	0.022	0.049	
4. LEXP/LOUT	1	0.017	0.02*	
	2	0.021	0.024	
	3	0.021	0.028	
	4	0.021	0.031	
	5	0.022	0.035	
	6	0.026	0.048	
	7	0.029	0.058	7

	8	0.021	0.047	
5. LY/LEXP	1	0.139	0.161	
	2	0.119	0.145	
	3	0.139	0.188	
	4	0.146	0.218	
	5	0.157	0.259	
	6	0.098	0.178	
	7	0.066	0.133*	
	8	0.722	0.145	
6. LEXP/LY	1	0.018	0.021	
	2	0.017	0.021*	
	3	0.021	0.029	
	4	0.024	0.034	
	5	0.022	0.036	
	6	0.025	0.046	
	7	0.026	0.052	7
	8	0.026	0.050	

* refers to the lag length which minimises both the AIC and SC. LOUT, LEXP, LGDP and LY stand for log of output, log of expenditure, log of GDP and log of yield respectively.

Appendix C

Estimated Coefficients

Table C1: Results obtained from model 5.1

	equation 1 (output/expenditure)		equation 2(expenditure/output)	
variable	coefficient	T-ratio	coefficient	T-ratio
LOUT1	-0.964	-2.720**	-0.177	-0.398
LOUT2	-0.991	-2.445**	0.100	-0.198
LOUT3	-0.968	-1.897**	0.114	0.177
LOUT4	-0.722	-1.274	0.571	0.802
LOUT5	-0.979	-1.552*	0.571	0.719
LOUT6	-1.191	-1.617*	0.440	0.475
LOUT7	-1.191	-1.617*	0.475	0.473
LEXP1	0.061	0.229	-0.179	-0.533
LEXP2	-0.332	-1.208	-0.266	-0.768
LEXP3	-0.264	-0.898	0.279	0.755
LEXP4	-0.318	-1.137	0.312	0.888
LEXP5	0.258	0.787	0.010	0.025
LEXP6	0.882	3.008**	0.278	0.753
LEXP7	-0.191	-0.371	0.112	0.173
LVHAT	-1.655	-1.953**	0.069	0.065

* and ** mean significant at 10 and 5 percent respectively. LOUT and LEXP are log of output and log of expenditure respectively. The numbers 1 to 7 represent the number of lags. LVHAT is the variable for coefficients of speed of adjustment (i.e. $\hat{v}_{t-8}$).

Table C2: Results obtained from model 5.2

	equation 1 (yield/expenditure)		equation 2(expenditure/yield)	
variable	coefficient	T-ratio	coefficient	T-ratio
LY1	-0.491	-2.123**	-0.062	-0.405
LY2	-0.607	-2.149**	-0.016	-0.084
LY3	-0.323	-1.184	-0.011	-0.062
LY4	-0.289	-1.113	0.115	0.673
LY5	-0.650	-2.368**	0.062	0.343
LY6	-0.378	-1.218	0.039	0.192
LEXP1	0.105	-0.177	-0.397	-1.014
LEXP2	-0.922	-1.507*	-0.307	-0.762
LEXP3	-1.424	-2.408**	0.281	0.722
LEXP4	-0.156	-0.254	0.397	0.983
LEXP5	2.066	3.370**	0.161	0.397
LEXP6	1.186	1.628*	0.096	0.199
LVHAT	-0.695	-1.915**	-0.064	-0.267

* and ** mean significant at 10 and 5 percent levels. LY is log of yield. Numbers 1 to 6, LEXP and LVHAT are as in table 5.4

Table C3: Results obtained from model 5.3

	equation 1 (GDP/expenditure)		equation 2(expenditure/GDP)	
variable	coefficient	T-ratio	coefficient	T-ratio
LGDP1	-0.685	-2.244**	0.355	0.949
LGDP2	-0.841	-3.219**	-0.037	-0.114
LGDP3	-0.586	-2.015**	0.199	0.559
LGDP4	-0.365	-1.387*	0.163	0.507
LGDP5	-0.689	-3.045**	0.134	0.483
LGDP6	-0.624	-2.358**	0.169	0.520
LEXP1	0.198	0.678	-0.247	-0.687
LEXP2	-0.765	-2.011**	-0.190	-0.500
LEXP3	-0.512	-1.330	0.652	1.381*
LEXP4	-0.643	-2.011**	0.337	0.861
LEXP5	0.940	2.513**	0.184	0.402
LEXP6	1.566	3.094**	-0.486	-0.783
LVHAT	-0.684	-2.084**	0.136	0.338

* and ** mean significant at 10 and 5 percent levels. LGDP is log of GDP. Numbers 1 to 6, LEXP and LVHAT are as in table 5.

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