ESTIMATION OF THE RATE OF RETURN TO WINE GRAPE RESEARCH AND TECHNOLOGY DEVELOPMENT EXPENDITURES IN SOUTH AFRICA

Rob Townsend[1] and Johan van Zyl[2]

This article evaluates the impact of research and technology development in the wine grape industry in order to determine the rate of return (ROR) to these investments, and to make specific recommendations on funding. The analysis illustrates the applied and adaptive nature of the research conducted in the industry, with RORs of roughly 40 percent for R&D and extension. This is high, providing excellent motivation for increased investment in R&D.

BEPALING VAN DIE OPBRENGSKOERS VAN NAVORSING EN TEGNOLOGIE-ONTWIKKELING IN DIE WYNDRUIFINDUSTRIE

Hierdie artikel evalueer die impak van navorsing en tegnologie-ontwikkeling in die wyndruifindustrie met die doel om die opbrengskoers op hierdie investerings te bepaal, asook om spesifieke aanbevelings rakende befondsing te maak. Die ontleding illustreer die toegepaste aard van navorsing in die industrie, met opbrengskoerse van ongeveer 40 persent vir navorsing en ontwikkeling en voorligting. Dit is hoog, wat 'n uitstekende motivering vir groter investering in navorsing en ontwikkeling verskaf.

1.   INTRODUCTION

Agriculture's importance in the process of economic growth highlights the critical role of sustained advances in farm production practices by improving the quantity and quality of farm products (Alston *et al*., 1995). In this context, investment in improved agricultural technology continues to be an important avenue of not only government assistance to specific sectors of the economy, but also for industries and farmers to fund research. However, the increased resource pressure facing governments, other donors and recipients have emphasised the need for the prior assessment of potential benefits of both research vision and individual projects to assist planning and management.

Based on the evidence that the rates of return to research and development investments were high and indicative of unnecessary conservative investment, support for agricultural research has been advocated by

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[1]   *Senior lecturer, Department of Agricultural Economics, Extension and Rural Development, University of Pretoria, Pretoria 0002.*

[2]   *Principal and Vice-chancellor, University of Pretoria, Pretoria 0002.*

numerous authors. Studies on South African agriculture suggest a rate of return of between 44% and 58% (Khatri *et al.*, 1995, 1996; Arnade *et al.*, 1996), which may justify (increased) investment in research. However, increasing monetary and fiscal pressure and high demand has resulted in strong competition for limited government funds. This changing environment has placed great emphasis on determining 'value for money in science', not only at the aggregate agricultural level but also at the individual crop level.

Disaggregated studies concentrating on individual crops, for example wine grapes, can provide useful information to decision makers seeking to determine the optimal allocation of their scarce resources. This article attempts to provide empirical evidence on the value of research for wine grapes in South Africa. The wine grape crop is one of the most significant in the agricultural economy, both historically and economically. It accounts for about 14% of the value of the horticultural sector, which is currently enjoying the highest growth rate in South African agriculture. It also generates a significant quantity of foreign exchange with the value of exports almost five times higher now than in 1990. South Africa produces 3.7% of total world production (1993) of wine grapes and ranks eighth in the world (KWV, 1996).

Within this context, the specific aims of this article are to evaluate and assess the impact of research and technology development in the wine grape industry in order to:

- determine the rate of return to these investments; and
- make specific recommendations on funding arrangements.

The reason for this research is clear: the wine grape market is highly competitive, particularly internationally. Relatively high local production costs and decreasing margins, therefore, necessitate research for developing cutting-edge technology to improve productivity and obtaining a comparative advantage *vis-à-vis* competitors in the industry. It has, however, not been scientifically established that the rate of return on research and technology development in the wine grape industry, both in South Africa or elsewhere in the world, is adequate to motivate continued or increased investments. This article concentrates on production-related research and development (R&D) and does not include wine-making.

The presentation is organised as follows: expenditures on research and extension in the wine grape industry are discussed first, followed by methodological issues of evaluating and assessing the impact of agricultural research. This is followed by a brief discussion of data used in the analysis

and deviations in yield of wine grapes over time. Determination of the appropriate lag structures used in the modelling is next, followed by calculations of the rate of return to R&D. Some recommendations conclude the article.

2.   RESEARCH AND EXTENSION IN THE WINE GRAPE INDUSTRY

Two institutions are responsible for the bulk of the R&D and extension within the South African wine grape industry. While there are no clear categories, with both institutions being involved in R&D and extension, most of the research on wine grapes is conducted at the Nietvoorbij Institute for Viticulture and Oenology of the Agricultural Research Council, while extension is almost exclusively conducted by the 'Kooperatiewe Wynbouersvereniging' (KWV). For purposes of this article, these two categories, although not necessarily correct, are used as the only sources of R&D and extension relevant to the wine grape industry.

This approach is not without problems. International research conducted elsewhere in the world may also impact on the South African wine grape industry. Therefore, an analysis of the returns to R&D should allow for both private spillovers from abroad and for the technology provided by multinational seed, chemical and machinery companies, which may or may not be performing their research in South Africa. This is usually done by using international patent counts or other measures to construct a 'knowledge stock' variable (Khatri, *et al*., 1996). In this case, however, it is assumed that these effects are negligible compared to the impact of local R&D, and it is therefore ignored. For the non-international private sector not related to Nietvoorbij and the KWV, very little is known about R&D. This is a handicap, but need not prevent economic analysis of the returns to R&D, since private R&D is not outside the market system, like public expenditures.

Indeed, as was noted by Griliches (1973), if agricultural inputs were supplied by a monopolist, and the input statistics took proper account of quality adjustments, technical change emanating from the private sector input industries would be fully included in the input series. Such technological changes are in the farm inputs sector, not the farm sector itself (Kislev and Peterson, 1982), and would not present any difficulties. It is only to the extent that the input suppliers are monopolistic competitors and that the statistical sources fail to measure inputs in efficiency units, that allowance must be made for private R&D expenditures. Due to these two factors, not all technical

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change in the input industries is correctly measured at source and there will be some spillover that is caught instead in measures of agricultural productivity. Thus, in estimating the returns to R&D, all the non-market public expenditures should be included on the cost side and some proportion of private expenditures should be added. In the case of South Africa and particularly wine grapes, however, statistics and market structure in the agricultural input industries are such that these effects can be considered negligible (see Van Zyl and Groenewald, 1988, for a discussion of market structure in input industries). Therefore, the assumption that Nietvoorbij and the KWV are the only sources of R&D and extension relevant to the wine grape industry has merit.

The increase in real expenditure on extension activities (by KWV) relative to R&D (by Nietvoorbij) can be seen clearly in Figures 1 and 2. KWV's expenditure (on extension) has the highest growth rate of the variables under consideration with an annual growth rate of 11.59%, even though this slowed towards the end of the sample to a rate 6.85% per annum (between 1987 and 1996). In contrast, Nietvoorbij's real research expenditure has a fairly constant growth rate.
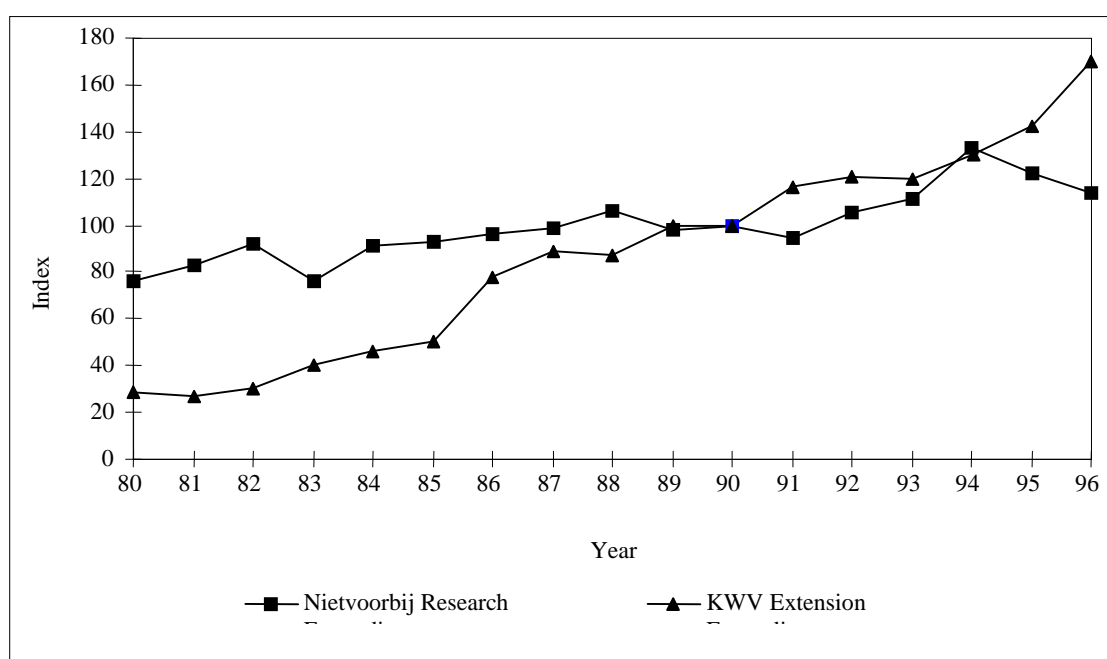

Figure 1:   Indices of Nietvoorbij's Research Expenditures and KWV's Extension Expenditures (Real Values)
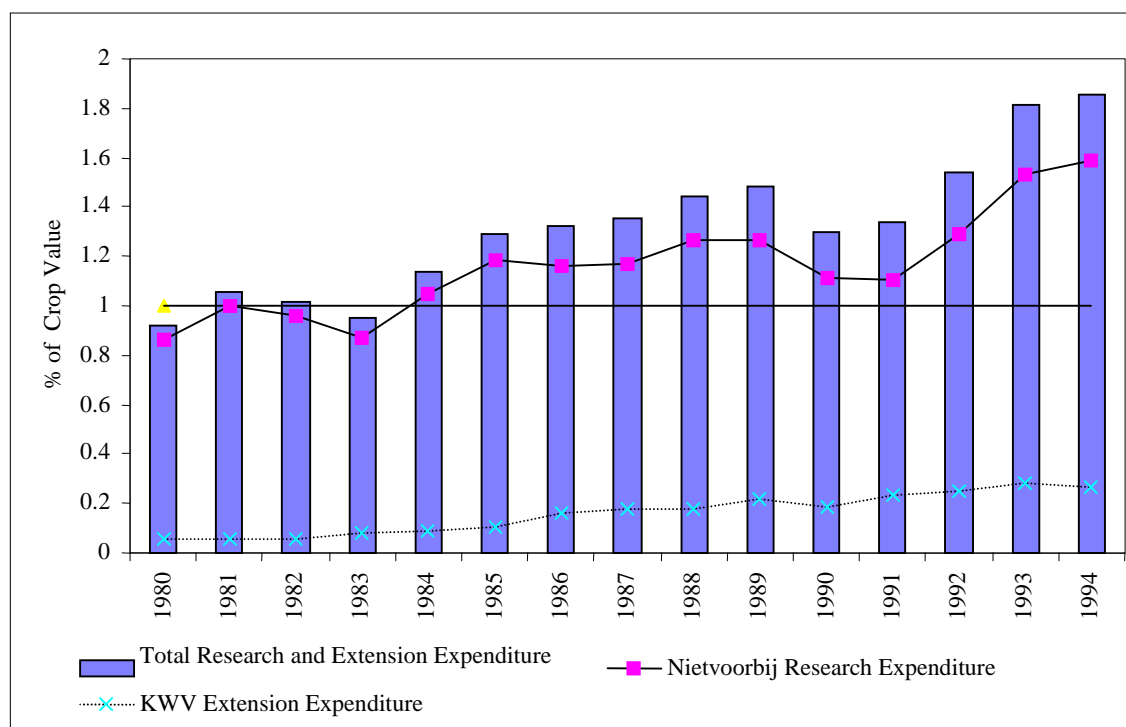
Figure 2:   Research and extension expenditures as a percentage of the value of the wine grape crop

The Agricultural Research Council (ARC) is the principal agricultural research entity in South Africa. It oversees operations in 16 research institutes with a network of experimental farms and a staff of approximately 4 150, including 672 professional researchers. This infrastructure is deployed throughout the entire country and undertakes R&D on all the major agricultural commodities in South Africa (with the exception of sugarcane). The Nietvoorbij Institute for Viticulture and Oenology is one of these research institutes with the responsibility for research on viticulture and oenology. Nietvoorbij has developed over the past 42 years into a world-renowned one-stop research facility, generating leading-edge technology for South African grape, wine and brandy industries. Research priorities are driven by producer needs and market demand. These priorities are determined in conjunction with the industries. It is situated within the major wine region, Stellenbosch, also having experimental farms in Paarl, De Doorns, Robertson and Lutzville, trial plots near Upington and co-operative trials on producer farms. ARC institutes have relatively little administrative autonomy.

Decisions regarding research priorities within the ARC are taken at the council level and funding for each institute comes via the central administration of ARC. Up to 1992, Government funded the total research effort in full. Since April 1992, commercial agriculture associated industries

and input suppliers had to pay in part for research conducted on their behalf. Presently, commercial agriculture pays for 22% of the research budget. However, the total external income budgeted for 1997/98 amounts to 32% due to income from selling farm produce, services rendered and consultations offered. The short-term aim is to receive 30% of total project cost from commercial agriculture. The Council receives an annual appropriation from the government, which still accounts for the bulk of its funds.

Nietvoorbij distinguishes itself for being probably the only facility in the world where all research pertaining to grapes and wine is executed under one roof. A capacity to serve small-scale farming on a multi-disciplinary basis has also been established. Nietvoorbij has five research divisions, namely soil science, wine grapes, table and raisins grapes, plant protection, and oenology. The duration of a typical project will be three to four years. The research conducted serves the wine, table and raisin grape industries of South Africa. Nietvoorbij employs a staff of 215 of whom 30 are researchers and 34 are research technicians. The balance includes laboratory assistants (13), data personnel, public relations officers, security officers, administrative and farm personnel and general assistants (138).

The 'Kooperatiewe Wynbouersvereniging' (KWV) was established in 1918 and represents more than 4 600 producers. It makes and markets wine and related products domestically and internationally. It also provides a wide range of specialist products and services to wine producers, the wine community and consumers. The KWV is a major player in the manufacturing and marketing of South African wines and related products. As service organisation, it also provides the wine industry, among others, with: extension on the growing of wine grapes; multiplying of the best plant material; and consulting services to all producers, co-operative cellars and broader wine industry by specialists on wine grape production, soil science, agricultural economics and manpower management. These services are provided at a cost. In addition, it publishes a specialised magazine aimed at the wine farmer.

3.   METHODOLOGICAL ISSUES OF ASSESSING THE IMPACT OF RESEARCH

The relationship between R&D expenditures and technology-based productivity growth in agriculture has attracted the attention of both historians and economists for some time, at least since the work of Griliches (1958). The progress in this field to date is well documented in Alston, Norton

and Pardey (1995), while the literature on the returns to R&D is surveyed by Echeverria (1990).

The majority of empirical rate of return (ROR) models reported are based on either *economic surplus* calculations, following Griliches (1958), or on *econometric estimation* of the output elasticity of R&D derived from the production relationship (also pioneered by Griliches, in the early 1960s). This article will focus on the production approach.

In the production function approach, the R&D elasticity is derived directly from estimation of a production, cost or profit function, with R&D included, or by first constructing a total factor productivity index, changes in which are then explained by the technology-related variables. In either case, it is the effect of the technology input on output or on the productivity of the sector adopting the technology that is measured.

This approach is taken because it is inherently difficult to measure the output of the R&D process directly. If the output is viewed as knowledge produced, then the obvious direct measure is publications (Evenson and Kislev, 1975). However, the knowledge produced usually has to be embodied in new technologies before it can affect productivity, which means that patents can be a useful measure of the technology produced by the R&D system (Griliches, 1984). The basic problem with both these measures is that quality adjustment of production is extremely important when determining the impact of R&D, an aspect which is not accounted for.[3]

The advantage of a production function is that it can be extended to include these technology variables. Thus, outputs, Y_i, are a function of traditional agricultural inputs, X_j, and the variables which shift the production function over time, T_k. The simplest form is the single output production function, $Y = f(X_j, T_k)$. The T vector normally accounts for technology. It includes lagged R&D expenditures, that generate new technology; extension expenditures that transmit the results to the farmers, so diffusing the technology; and the education level of the farmers, which affects both their own creative and managerial abilities, and their skill in appraising and adapting exogenous technologies. The weather is also normally included, as it explains some of the residual errors. In addition, several other variables have also been used in the extensive literature.

The Basic Production Function Approach

Simple econometric techniques, using linear regression analysis, have been in

use at least since 1928, when Cobb and Douglas fitted a production function to data for the US manufacturing industry. Griliches (1963, 1964) included agricultural R&D expenditures, extension expenditures and education as explanatory variables to explain the shifts in the agricultural production function over time. The data used were three cross sections of thirty-nine US states, at five-yearly intervals, taken from the US agricultural census. The functional form used was the ubiquitous Cobb-Douglas.

By assuming that X and Y represent inputs and output, respectively, in a production function, the inclusion of the logarithm of R&D and extension expenditures (T) in the Cobb-Douglas gives

$$LnY = Ln\,\alpha_0 + \alpha_1\,LnX_1 + \alpha_2\,LnX_2 + ... + \alpha_n\,LnX_n + \alpha_T\,LnT \qquad (1)$$

where $X_1,...,X_n$ are the respective input variables and $\alpha_1,..., \alpha_n$ are the coefficients (elasticities) to be estimated. Equation (1) is linear in logarithms, so that the coefficient of T (α_T) is the output elasticity of R&D and extension expenditures. Griliches (1964) found that R&D and extension together accounted for about 5 percent of the change in output for his sample of US farms. This simple approach is still useful. A recent application to 22 countries in Sub-Saharan Africa over the period 1971-1986 by Thirtle, Hadley & Townsend (1995) shows how it can be extended using panel data. In this study, agricultural output is explained by three traditional inputs (land, labour and livestock), two modern inputs (fertiliser and machinery), investments in infrastructure (irrigation and machinery), public R&D, extension and education, and the real protection coefficient, which represents the policy environment.

A similar simple production function model is used in this study to evaluate the returns to research expenditure. The more complex and data intensive profit function was not used due to data limitations. These are described in the next section.

4.   DATA

Both aggregate and farm management data are used in the analysis. The aggregate data were obtained from the *Abstract of Agricultural Statistics,* the South African Wine Industry Statistics, published by KWV, and unpublished data from KWV and the Nietvoorbij Institute for Viticulture and Oenology of the Agricultural Research Council. The farm surveys consisted of farm

production data collected by the KWV in the Orange River, Olifants River, Klein Karoo, Malmesbury and Paarl, Robertson, Stellenbosch and Worcester regions over a ten-year period from 1987-1996. This provides a (7 by 10) panel of data with variations between regions and over time.

Similar to most conventional production function studies, this analysis uses yield per unit area as the dependent variable. Inputs and technology variables are used to explain deviations in yield per unit area. The plot of the wine grape yield (tons per hectare) index in Figure 3 shows no substantial increase over the time period under consideration. This, at first appearance, suggests that the technology effects on wine grapes have been minimal.
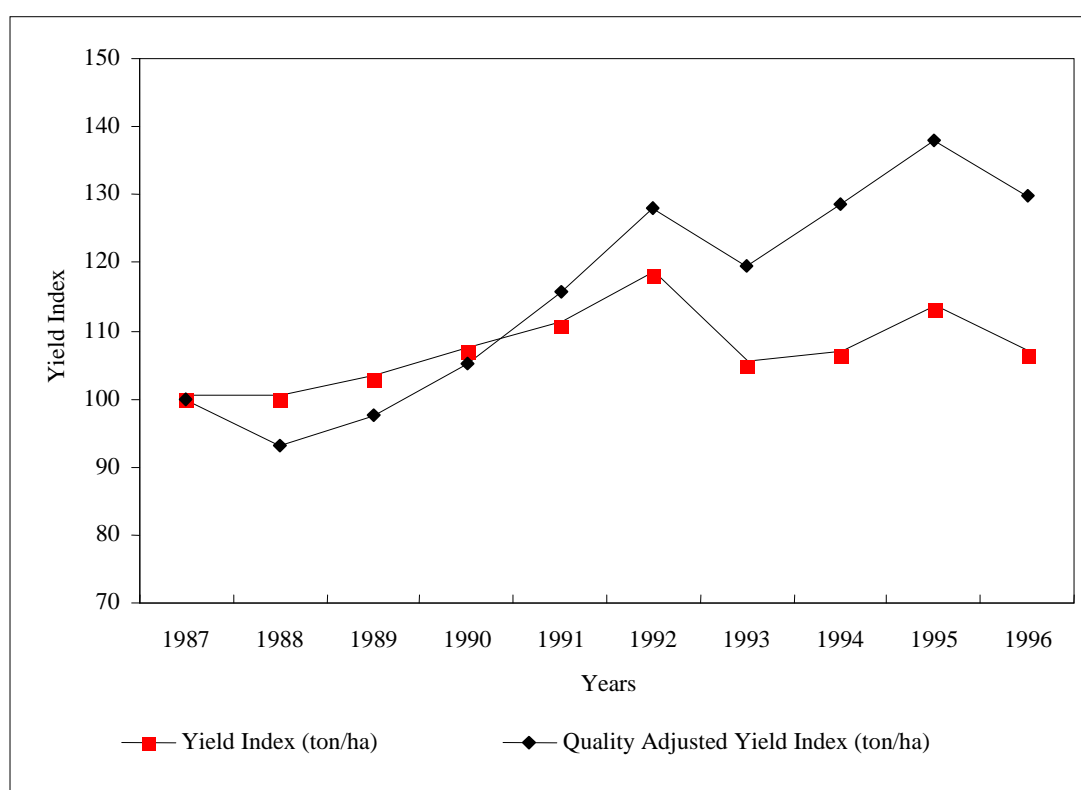

Figure 3:   Aggregate yield and quality adjusted yield

However, as is common to many crops, research is also focused on increasing the quality of the product as opposed to concentrating solely on the yield. An example of this quality improving research conducted at Nietvoorbij is the testing of wine grape cultivation methods under different soil and climate conditions together with identification of regions with a specific potential for the production of high quality wine of different styles. In order to capture this improvement, the yield series must be adjusted for quality changes. A quality-adjusted index was created by taking into account the increasing proportion

of good wine produced. This was done by dividing the value of good wine by the total value of wine. An increase in this ratio is a reflection of higher quality. This index was then normalised to one (1) in 1987, and multiplied by the yield to derive a quality adjusted yield index. The resulting quality adjusted series is also shown in Figure 3. This series increases at a much faster rate than the unadjusted yield. Over the sample period the area planted to wine grapes has not changed significantly.

Both yield series in Figure 3 show substantial annual variations. This is to be expected, as weather has a major effect on yields. Data obtained from the KWV to construct a weather index support this notion. The weather index incorporates several relevant variables, including rainfall, humidity, temperature, wind, etc. These variables have been used by the KWV in the past to predict the total size of the wine grape harvest with a high degree of reliability, and are used in a similar manner to construct the weather index. The fluctuations in the weather index presented in Figure 4 are seen to be highly significantly correlated with the yield indices (r=0.83; p<0.01), which is a reflection of the large impact weather has on wine grape yields.
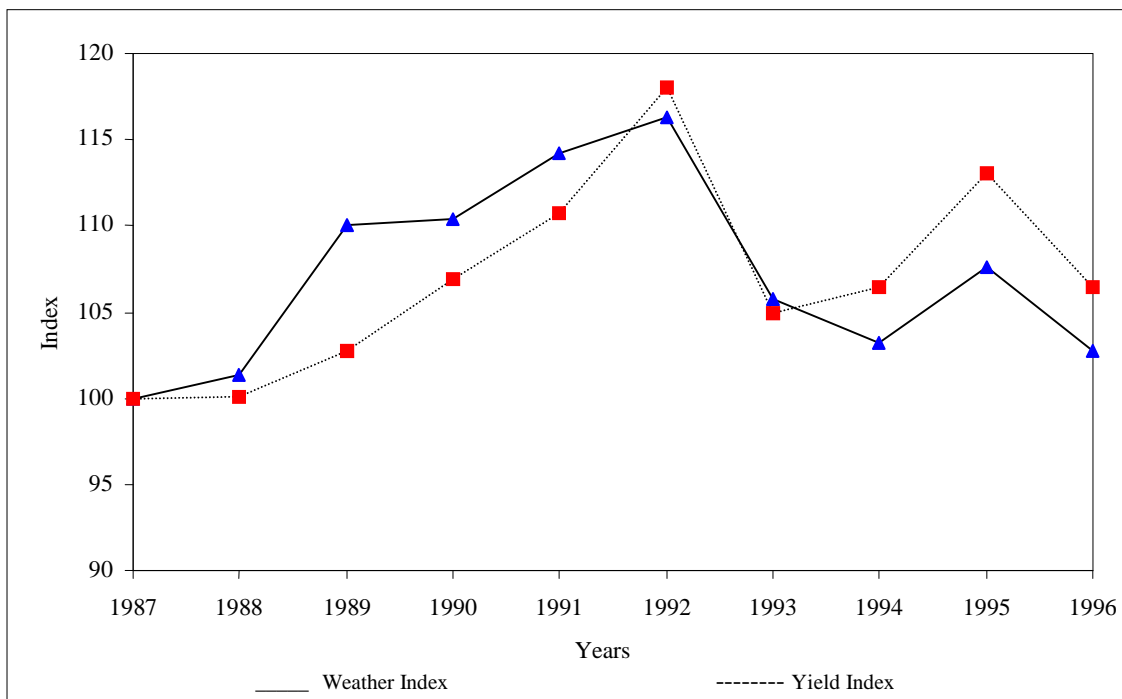

Figure 4:   Correlation of weather and yield indices

5.   MODELLING THE LAG STRUCTURE

There usually is a lag between R&D expenditures and productivity growth. Because lagged values of R&D are likely to be highly correlated, and use up too many degrees of freedom in econometric estimation, a distributed lag structure is often assumed. This is normally an inverted V or a second degree Almon polynomial lag, which is an inverted U-shape. The underlying reasoning is that the average R&D expenditure has little immediate effect (Khatri *et al.*, 1995).

This type of function has been fitted to data for U.S. agriculture by Evenson (1967, 1968), Cline & Lu (1976), Lu, Quance & Liu (1978), Lu, Cline & Quance (1979), Knutson & Tweeten (1979), Evenson, Waggoner & Ruttan (1979) and White & Havlicek (1982); to Australian data by Hastings (1981); to UK agriculture by Doyle & Ridout (1985) Thirtle & Bottomley (1989); and to the commercial sector farms in Zimbabwe by Thirtle *et al.* (1993). Khatri *et al.* (1995; 1996) and Townsend (1997) used this approach for South African case studies.

In order to capture lagged effects of R&D on productivity change or yields, and to avoid the collinearity problem of the unrestricted lag model, a common approach is to use an Almon polynomial lag (Evenson, 1967; Knutson and Tweeten, 1979; Doyle and Ridout, 1985; Thirtle and Bottomely, 1988, 1989). The polynomial form is popular due to its empirical simplicity, providing a smooth and feasible form. However, the specification may require restrictions. The validity of these restrictions has been questioned, particularly end point restrictions Hallam, 1990). In particular, there are suggestions that these models may lead to biased estimates of the effects of research spending. To avoid these biased results, less restrictive forms such as the beta and gamma distributions (derived from the Pearson representation), as well as the unrestricted model, can be used.

The equation used to determine the appropriate lag structure is:

$$\ln YIELD_t \;=\; \ln \alpha_0 \;+\; \ln \alpha_1 WEATHER \;+\; \sum_{i=1}^{n} \beta_i \ln RD_{t-i} \;+\; u_t \qquad (2)$$

where YIELD is the tons per hectare of wine grapes, RD is the research expenditure and WEATHER is the weather index. β is the elasticity of R&D at various lag lengths where n is the maximum lag of R&D that affects YIELD. u_t is the residual which accounts for all the deviations in yield not explained by the model. Conventional inputs, such as fertiliser, may also be expected to

affect yields. However, due to a 'degrees of freedom' problem, all the conventional inputs could not be included. Although rate of return (ROR) calculations in this article are made on the basis of estimating equations that do not include conventional inputs (see Akgungor *et al.*, 1996 for a recent example), Alston *et al.*, 1995:107) correctly argue that conventional inputs should normally be included. This is a potentially serious problem, which could bias the R&D elasticity upwards and inflate the ROR. This is addressed later in the analysis.

Equation (2) was used to determine the lag structure, which will be imposed on the data and used in the panel estimation to calculate a rate of return to R&D. Estimation of the lag coefficients of R&D using an unrestricted functional form (lag structure) with many lag terms, gives positive and negative coefficients because of collinearity problems. However, providing that the ordinary least squares (OLS) assumptions are satisfied, the sum of the unrestricted lag coefficients should be an unbiased estimate of the total elasticity. In this respect, the polynomial functional form for calculating lags is popular due to its empirical simplicity. However, these models may lead to biased estimates of the effects of research spending on the one hand (Hallam, 1990). On the other hand, the advantage of the polynomial form in this situation is that it saves degrees of freedom. For example, a second order polynomial, irrespective of the number of lags of R&D included, uses only three degrees of freedom.

The polynomial lag model was estimated with no restrictions, and near end, far end and both end points restricted to equal zero. These restrictions were applied to second, third and fourth order polynomials for a range of lag lengths. The Schwarz and Akaike Criteria indicated a 4-year lead-time, with a second-degree polynomial with both end point restrictions for the unadjusted yield equation. For the quality adjusted yield equation, these criteria suggested a second-degree polynomial with end point restrictions and a lag of 7 years. Simple t-tests of the significance of alternative lags were consistent with these results. Table 1 shows these two contrasting lag structures between the yield and the quality-adjusted yield.

Figure 5 shows a four-year lead-time for research expenditure to impact on unadjusted yields. When the yields are adjusted for quality, the lag structure changes to that shown in Figure 6; there is no lead-time with research already having an impact in the current year. This could reflect the value of the more direct impact of improving quality of the crop, as opposed to improving only yields. As mentioned earlier, Nietvoorbij has specific projects to improve quality such as the development and testing of wine grape cultivation

methods under different soil and climatic conditions together with identification of regions with a specific potential for the production of high quality wine of different styles.

Table 1:   Polynomial Lag Distributions

| Variables	Nietvoorbij Research Expenditures[1]	
	Yield	Quality Adjusted Yield
Constant	-0.119 (-014)	1.646 (0.86)
Weather Index	0.6309 (3.49)	0.3348 (0.83)
$R\&D_t$	-	0.12799 (5.97)
$R\&D_{t-1}$	-	0.22389 (5.97)
$R\&D_{t-2}$	-	0.28786 (5.97)
$R\&D_{t-3}$	-	0.31985 (5.97)
$R\&D_{t-4}$	0.08525 (2.85)	0.31985 (5.97)
$R\&D_{t-5}$	0.12787 (2.85)	0.28786 (5.97)
$R\&D_{t-6}$	0.12787 (2.85)	0.22389 (5.97)
$R\&D_{t-7}$	0.08525 (2.85)	0.12799 (5.97)
SUM	0.426	1.919
R^2	0.74	0.80
Durbin-Watson	2.41	1.51

[1] Values in brackets represent t-values
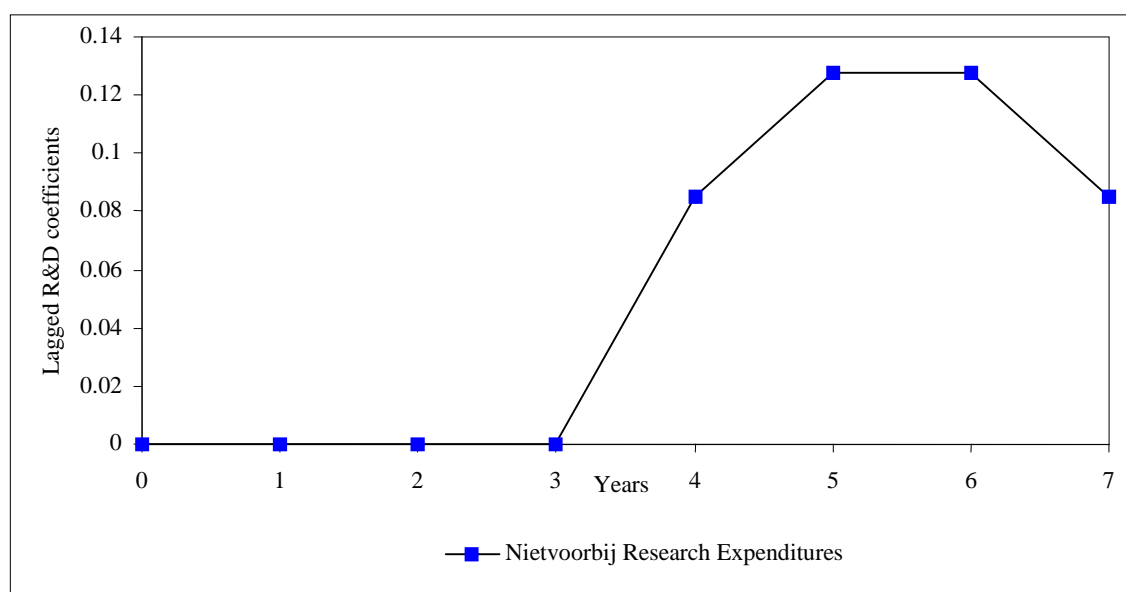
Figure 5:   Lag structure of R&D effects on yield (not quality adjusted)

As shown in Figure 6, the research impact. reaches a peak after about three to four years after which it declines. This decline relates only to the expenditure in year 0. The expenditure in year 1 will have the same structure and so will peak in year 4 to 5 in Figure 6. This will maintain the research effect on yield at a peak as the effect of the expenditure in year 0 is superseded by the equation in year one.
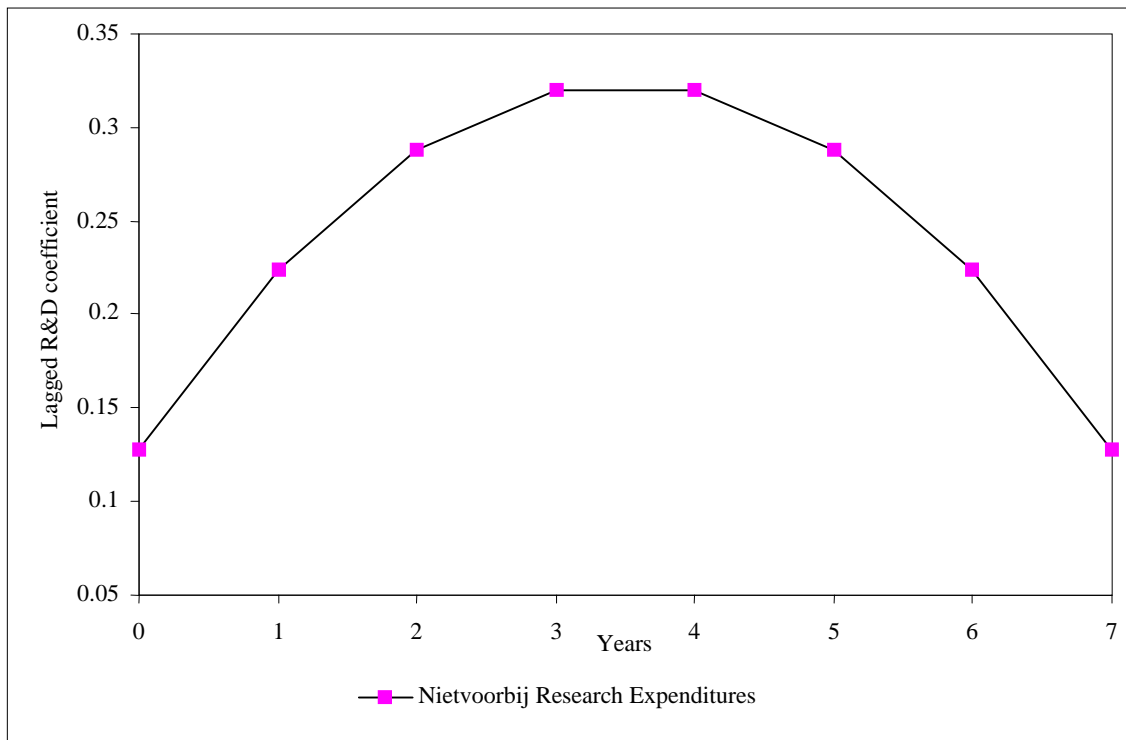

Figure 6:   Lag structure of R&D effects on quality adjusted yield

6.   CALCULATING THE RATE OF RETURN

The lag structure in the polynomial model identifies the effects of changes in R&D expenditures on wine grapes and can be used to calculate the rate of return. In order to derive a rate of return, the elasticities (Table 1) have to be converted to value of marginal products, using the procedure in Thirtle and Bottomley (1988) described below. Each lag coefficient, β_i is the output elasticity of R&D for that year:

$$\beta_i = \frac{\partial \ln \text{OUTPUT}_t}{\partial \ln \text{RD}_{t-i}} = \frac{\partial \text{OUTPUT}_t}{\partial \text{RD}_{t-i}} \cdot \frac{\text{RD}_{t-i}}{\text{OUTPUT}_t} \qquad (3)$$

Thus, the marginal physical product of R&D is the elasticity multiplied by the average physical product:

$$MPP_{t-i} \; = \; \frac{\partial OUTPUT_t}{\partial RD_t} \; = \; \beta_i \frac{OUTPUT_t}{RD_{t-i}} \qquad (4)$$

Replacing $YIELD/RD_{t-i}$ by its geometric mean, and changing from continuous to discrete approximations gives:

$$\frac{\Delta OUTPUT_t}{\Delta RD_{t-i}} \; = \; \beta_i \frac{\overline{YIELD}}{\overline{RD}_{t-i}} \qquad (5)$$

Then, multiplying by the increase in the value of output divided by the change in quantity converts from output quantity to output value. Thus, the value marginal product of R&D in period *t-i* can then be written as:

$$VMP_{t-i} \; = \; \frac{\Delta VALUE_t}{\Delta RD_{t-i}} \; = \; \beta_i \frac{\overline{OUTPUT}}{\overline{RD}_{t-i}} \cdot \frac{\Delta VALUE_t}{\Delta OUTPUT_t} \qquad (6)$$

where $YIELD/RD_{t-i}$ is an average and $\Delta VALUE_t/\Delta YIELD_t$ is calculated as the average of the last five years minus the average for the first five years, for both variables. Thus, these are constants, but β_i varies over the lag period, giving a series of marginal returns resulting from a unit change in R&D expenditure. The value of output, $\Delta VALUE_t/\Delta YIELD_t$ is the geometric mean calculated using the value of output at constant 1995 prices. Similarly, $YIELD/RD_{t-i}$ is a constant-price geometric average. The marginal internal rate of return (MIRR) is calculated from:

$$\sum_{i=1}^{n} \frac{VMP_{t-i}}{(1+r)^i} - 1 = 0 \qquad (7)$$

where *n* is the lag length, by solving for *r* (the MIRR). Table 2 shows the results.

Panel data estimation

Alternatively to the above methodology, one can estimate rates of return by imposing the lag structure and generating a coefficient for the effect of R&D expenditures on yield using the panel data set. This provides more degrees of

freedom, and allows the conventional inputs to be taken into account, which is important as the technology developed may result in less inputs being used. This provides a check for the ROR obtained using the above procedures, and addresses some of the criticisms centring on omission of conventional inputs.

Panel data estimation has the advantage of giving ample degrees of freedom. In addition, both the cross sectional and time series variances help to determine the parameter estimates. The disadvantage of panel data estimation is in terms of imposing restrictions, as the three alternative models below show. The pooled OLS equation,

$$Y_{it} = \alpha + \beta X_{it} + u_{it}, \quad i.e. \ \alpha, \beta = \alpha_{it}, \beta_{it} \tag{8}$$

implies that both the intercepts, α, and slope coefficients, β, are the same for all wine regions (which is unrealistic given the variation between regions). Furthermore, the fixed effects model (FEM),

$$Y_{it} = a_{it} + bX_{it} + u_{it} \quad i.e. \ a_{it}, b = a_{it}, b_{it} \tag{9}$$

assumes that the intercepts, α_{it}, vary, but the slope coefficients, β, are the same. (This is equivalent to least squares with dummy variables (LSDV)). The random effects model (REM) allows for a random region-specific effect to enter the equation through the error term,

$$u_{it} = \mu_i + e_{it}, \quad \text{where} \quad Var(\mu_i) = \sigma_\mu^2, \ Var(e_{it}) = \sigma_2^2 \tag{10}$$

It is clear that the first model (the pooled OLS equation) is not appropriate where regions differ considerably in their yield potential. However, all three of these models were estimated using the sample survey data for ten years. A production function was estimated with yield as the dependent variable and intermediate inputs (fertiliser, pesticides, etc.), labour, machinery, miscellaneous inputs (water, electricity, etc.), weather, and research and development (R&D) expenditures. The latter two variables were assumed to be similar for all regions, while the first four variables were region specific.

As expected, the pooled ordinary least squares model was rejected on basis of the poor statistical fit in favour of the FEM/LSDV and REM models. The

coefficients on the R&D variables were subsequently retrieved from the latter two models and rates of return were calculated (see Table 2).

Table 2:   Marginal internal rates of return on research and technology and extension investment in the SA wine grape industry (%)

Model	Nietvoorbij Research Expenditure + KWV Extension Expenditure	
	Yield	Quality Adjusted Yield
Aggregate Production Function	20	45
Fixed Effects	21	42
Random Coefficients	24	42

7.   CONCLUSIONS AND RECOMMENDATIONS

The most important conclusions following from the analysis are: First, the relative short lead time and lag structures clearly indicate that R&D in the wine grape industry is problem-oriented and adaptive in nature, *i.e.* there is a relatively short time lapse between investment in R&D and obtaining results. The example of the integrated pest management project on pheromones is a case in point, where applied research yielded positive effects within a relative short time span. Second, the different methodologies used to estimate RORs yield remarkably similar results in comparable scenarios. This implies that the results can be used with confidence as they appear to be reliable and robust. Third, there are large differences in the rate of return to research derived from unadjusted yield and quality adjusted yield. This suggests that much of the research undertaken has also resulted in improved quality of the product and not only the yield alone. This is, for example the case in the terrain identification project, where wine grape quality is linked to soil and other characteristics.

These results compare well with other studies determining the time lag between R&D investment and positive yield effects, and measuring rates of return to agricultural R&D, both in South Africa and elsewhere in the world. The lead time and lag structure for wine grapes are shorter than that for both South African and British agriculture as a whole, while the returns to R&D and extension is comparable (see Khatri, *et al.*, 1996; Van Zyl, *et al.*, 1997). The ROR is also higher than for maize in South Africa (Townsend, 1997).

The results obtained from this study have several policy and other implications. At the broad policy level relating to the funding of research, two issues stand out: (i) The relatively high RORs indicate that R&D expenditures

could be increased substantially. At present, a relatively low percentage of the total value of wine grape production is invested in R&D (see Figure 2). This is lower than that for agriculture as a whole, and lags considerably behind R&D expenditures of countries like the USA and Australia. (ii) The high return on R&D benefits mainly wine grape farmers. The RORs are considerably higher than that usually required from public investments, indicating that there is a case for increasing public expenditure on these items. Moreover, the magnitude of the benefits and nature of the industry imply that it also makes good economic sense for the beneficiaries, *i.e.* the wine farmers, to contribute to R&D.

At the level of research focus, the major effects of weather on yields has to be noted. This indicates that research minimising the negative effects of weather should be encouraged, as it will impact positively on the industry, particularly the farmers.

The findings also have implications for future work in the wine grape industry (and other industries). While there are several well-developed methods for measuring the impact of and return on agricultural R&D, data availability usually provides a problem. This also applies to the wine grape industry. The lack of time-series and project specific data is a serious limitation to rigorous economic analysis. This should be addressed in two ways: (i) existing data should be systematically gathered and compiled into appropriate series while there is still some institutional memory on project details in order to facilitate analysis of the impact of R&D; and (ii) all aspects of existing and future projects should be adequately recorded in a systematic way as an important part of each project. This will also allow for analysis of specific projects which is not always possible given the present paucity of data. Proper documentation of data will yield reliable analysis, which in turn could form the basis for the better allocation of scarce resources between different initiatives, both within the industry and between industries.

NOTES

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2.   This is simply the proportional change in physical output that results from a proportional change in the R&D input. Once the effect of R&D has been measured in this way, if R&D expenditures are known and the

value of output can be calculated, it is possible to produce a rate of return to the investment in R&D.

3.   This aspect is particularly important in the South African wine grape industry. The treatment of quality adjustment in wine grape yields in this study is covered in more detail later on.

REFERENCES

AKGUNGOR, S., MAKANDA, D., OEHMKE, J., MYERS, R. & CHOE, Y. (1996). A dynamic analysis of Kenyan wheat research and rate of return. *Proceedings of the Global Agricultural Science Policy for the Twenty First Century Conference*, Melbourne, Australia: August.

ALSTON, J.M., NORTON, G.W. & PARDEY, P.G. (1995). *Science under scarcity: Principles and practice for agricultural research evaluation and Priority Setting.* Cornell University Press, Ithaca and London.

ARNADE, C., SCHIMMELPFENNIG, D., THIRTLE, C. & VAN ZYL, J. (1996). Short and long-run returns to agricultural R&D in South Africa. *Proceedings of the Global Agricultural Science Policy for the Twenty First Century Conference*, Melbourne, Australia: August.

CLINE, P.L. & LU, Y.C. (1976). Efficiency aspects of the spatial allocation of public sector agricultural research and extension in the United States. *Regional Science Perspectives*, 6:1-16.

DOYLE, C.J. & RIDOUT, M.S. (1985). The impact of scientific research on UK agricultural productivity. *Research Policy*, 14:109-116.

ECHEVERRIA, R.G. (Ed.) (1990). *Methods for diagnosing research system constraints and assessing the impact of agricultural research,* Vol.2., ISNAR : The Hague.

EVENSON, R.E. (1967). The contribution of agricultural research to production. *Journal of Farm Economics*, 49:1415-1425.

EVENSON, R.E. (1968). *The contributions of agricultural research and extension to agricultural productivity.* Unpublished Ph.D. Dissertation, University of Chicago, Chicago.

EVENSON, R.E. & KISLEV, Y. (1975). *Agricultural research and productivity.* Yale University Press, New Haven.

EVENSON, R.E. & KRAMER, J. (1988). *Returns to R&D with policy effects.* Paper presented at the American Agricultural Economics Association Conference, Knoxville.

EVENSON, R.E, WAGGONER, P.E. & RUTTAN, V.W. (1979). Economic benefits from research : An example from agriculture. *Science*, 205:1101-1107.

GREENE, W.H. (1993). *Econometric analysis*. Second edition. Macmillan, New York.

GRILICHES, Z. (1958). Research costs and social returns : Hybrid corn and related innovations. *Journal of Political Economy*, 66:419-431.

GRILICHES, Z. (1963). The sources of measured productivity growth : US agriculture, 1940-60. *Journal of Political Economy*, 71: 331-346.

GRILICHES, Z. (1964). Research expenditures, education, and the aggregate agricultural production function. *American Economic Review*, LIV:691-674.

GRILICHES, Z. (1973). Issues in assessing the contribution of R&D to productivity growth. *Bell Journal of Economics*, 10(1):92-116.

GRILICHES, Z. (1984). *R&D, Patents and productivity*, University of Chicago Press, Chicago.

HALLAM, D. (1990). *Econometric modelling of agricultural commodity markets*. Routledge, London.

HALLAM, D. (1990). Agricultural research expenditures and agricultural productivity change. *Journal of Agricultural Economics*, 41:434-439.

HASTINGS, J. (1981). The impact of scientific research on Australian rural productivity. *Australian Journal of Agricultural Economics*, 25:48-59.

KHATRI, Y. (1994). *Technical change and the returns to research in UK agriculture, 1953-1990.* Unpublished Ph.D. thesis, University of Reading, United Kingdom.

KHATRI, Y., THIRTLE, C. & VAN ZYL, J. (1995). South African agricultural competitiveness :A profit function approach to the effects of technology. In:

Peters, G.H. and Hedley, D.D. (eds.) *Agricultural Competitiveness: Market Forces and Policy Choice*, Dartmouth Publishing, Aldershot: 670-684.

KHATRI, Y., THIRTLE, C. & VAN ZYL, J. (1996) Public research and development as a source of productivity change in South African agriculture. *South African Journal of Science*, 92:143-150.

KISLEV, Y. & PETERSON, W.L. (1982). Prices, technology and farm size. *Journal of Political Economy*, 90: 578-595.

KNUTSON, M. & TWEETEN, L.G. (1979). Toward an optimal rate of growth in agricultural production research and extension. *American Journal of Agricultural Economics*, 61:70-76.

KWV. (1996). *Statistics in the wine industry, 1996*. KWV, Paarl.

LU, Y., CLINE, P. & QUANCE, L. (1979). *Prospects for productivity growth in US agriculture.* Agriculture Economic Report No. 435, ESCS, USDA, Washington, D.C.

LU, Y., QUANCE, L. & LIU, C.L. (1978). Projecting agricultural productivity and its economic impact. *American Journal of Agricultural Economics*, 60:976-80.

THIRTLE, C., ATKINS, J., BOTTOMLEY, P., GONESE, N. & GOVEREH, J. (1993). The efficiency of agriculture in Zimbabwe, 1970-89. *Journal of International Development*, 5.

THIRTLE, C. & BOTTOMLEY, P. (1988). Is publicly funded agricultural research excessive? *Journal of Agricultural Economics*, 39:99-111.

THIRTLE, C. & BOTTOMLEY, P. (1989). The rate of return to public sector agricultural R&D in the UK, 1965-80. *Applied Economics*, 21:1063-1086.

THIRTLE, C., HADLEY, D. & TOWNSEND, R. (1995). A multilateral malmquist Productivity index approach to explaining agricultural growth in sub-Saharan Africa. *Development Policy Review*, 10(3):323-348.

TOWNSEND, R. (1997). *Policy distortions and agricultural performance in the South African economy*. Unpublished Ph.D. Thesis, University of Pretoria, Pretoria.

VAN ZYL, J. & GROENEWALD, J.A. (1988). The effects of protection on South African agriculture. *Journal of Agricultural Economics*, 39(3): 387-401.

VAN ZYL, J., THIRTLE, C. & BOTHA, C.A.J. (1997). Productivity change in South African commercial agriculture : An evaluation of the returns to investment in public agricultural extension. *South African Journal of Agricultural Extension*, 25: 1-11.

WHITE, F.C. & HAVLICEK, J. (1982). Optimal expenditures for agricultural research and extension : Implications of underfunding. *American Journal of Agricultural Economics*, 64:47-55.