AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

REFINING RETURNS TO RESEARCH AND DEVELOPMENT IN SOUTH AFRICAN COMMERCIAL AGRICULTURE

Y. Khatri
London School of Economics

D. Schimmelpfennig,
United States Department of Agriculture

C. Thirtle
University of Reading

J. van Zyl
University of Pretoria

Use of a long-run profit function provides accurate estimates of returns to agricultural R&D in Europe and North America, a result that is tied to the long term basic and applied nature of the research institutions in these areas. Agricultural R&D in South Africa is fundamentally different with a more adaptive character, resulting in a shorter lag of five years between research spending and changes in TFP. In this situation, the long-run profit function input demand and output supply elasticities are too high, resulting in overestimation of returns to R&D. A potential solution to this problem is to use a short-run profit function in the calculation of returns to R&D. Several other inputs are held fixed and the result is a short-run return to R&D in South Africa that compares favourably with long-run return levels that have been established for the northern hemisphere.

1. INTRODUCTION

In this paper, the profit function approach to estimating agricultural productivity and returns to agricultural R&D in South Africa is refined by comparing the returns from a short-run profit function to the returns from a long-run profit function.

Productivity statistics compare agricultural inputs to outputs in order to measure the performance of the sector. The ratio of aggregate output to an aggregate of all inputs combined gives a measure of total factor productivity (TFP). "Explaining" TFP growth, using non-conventional inputs such as R&D and extension expenditures, has been the topic of a large number of studies (listed in Echeverria, 1990). Changes in the TFP index are usually explained by determining or conditioning variables, such as the stock of knowledge (accumulated research capital, generated by past research expenditures), extension services and farmer education, as well as changes in weather.[1] The basic argument is that R&D generates technology, extension diffuses it and better-educated farmers are better at screening new technology. Consequently, they adopt technologies more quickly and also adapt technology, thereby adding an element of on-farm technology generation. For South Africa, spillovers through international technology transfers may also be important and the influence of the weather is considerable, so a weather index should reduce the unexplained errors.

There are essentially two approaches to explaining changes in agricultural productivity, which forms the basis for calculating the returns to R&D. Evenson, et al. (1987) call these the *integrated approach* (where the productivity-enhancing, or conditioning, factors are included directly in a primal or dual representation of production) and the *two-stage decomposition*, in which changes in total factor productivity (TFP) are first calculated, and then explained, in a second stage, by the factors, such as R&D and extension, that are thought to account for growth. The dual *integrated approach* has the advantage of minimising restrictive separability assumptions, as well as avoiding the need for the assumptions of full static equilibrium, Hicks neutral technical change and constant returns to scale, which are implicit in the two-stage approach.[2]

The paper consists of the following sections: determination of the distributed lags for the technology variables; the model; data; results (shadow prices and calculation of the returns to R&D; and a conclusion.

2. DETERMINING THE DISTRIBUTED LAGS FOR THE TECHNOLOGY VARIABLES

The effects of the technology variables on TFP growth are not immediate. There are several alternatives for modelling the lagged variables, but including numerous lagged values of R&D and patents, plus shorter lags for extension and education is not feasible, due to lack of degrees of freedom and collinearity. Including the technology variables in the estimation of the residual profit function is less restrictive than the two-stage approach, but the model is too complex and has insufficient degrees of freedom to allow much in the way of testing for the best formulation. Thus, the lags and depreciation rates in many previous studies have often been chosen somewhat arbitrarily.

In this case, the lag structures are predetermined, by resorting to the usual alternative two-stage methodology (Thirtle and van Zyl, 1994), which incorporates all the inputs and outputs in a total factor productivity index, changes in which are then explained by the technology variables--domestic R&D, international technology spillovers, extension, education and the weather. This implicitly imposes restrictions on the model, but allows testing of the lag structures, which can be modelled explicitly. We first explain the procedure, as if R&D were the only lagged variable and then discuss the complications caused by the fact that extension, patents and farmer education also have lagged effects. The TFP growth calculations of Thirtle et al (1993) reported above were used for this analysis.

The first stage of the analysis is to determine the length of the lag by estimating an unrestricted finite lag model, with

lag length k. Using fewer lags than the 'true' specification implies biased estimates and too many lags implies inefficient estimates. To estimate the lag length two approaches can be employed. The usual approach is that of searching over a range of k using appropriate model selection criteria. Geweke and Meese (1981) investigate various model selection criteria for this purpose, including the Akaike information criterion (AIC), the final prediction error (FPE), the Bayesian estimation criterion (BEC) and the Schwarz Criterion (SC). The tests are not always in agreement, but for the R&D lag all suggested nine or ten lags.

Then, the shape of the lag distribution must be determined. The conventional approach is to fit a function such as an inverted "U"-shaped second degree polynomial, but this formulation fitted the South African data poorly. Amongst the large number of alternative lag structures fitted, generalisations of the Beta and Gamma distributions (Tsurumi, 1971 and Schmidt, 1974) gave the best results according to the same model selection criteria (Adjusted R^2>0.77 in both cases). The best fit is negative skew with peak effects at one to four lags. Figures 1 and 2 provide the details.

This result can be contrasted with similar tests for the UK system, where the lag was sixteen years and the distribution was positively skewed, with the peak effects at twelve to sixteen lags (Khatri, 1994). This suggests that whereas the UK system includes a high proportion of basic scientific research with a long gestation period, the South African research system is dominated by short-term developmental work.[3]

In the profit function, which is described in the next section, the lag distribution is represented by a knowledge stock constructed using the perpetual inventory model (PIM), which is a reasonable approximation of the "true" lag structure. Thus, the knowledge stock (KS), with R&D entering with a one period lag, at period t is

$$KS_t = RD_{t-1} + (1-\delta)\, K_{t-1} \qquad (1)$$

where d is the rate of depreciation, which is set at 10%, so that 90% of the weight is on the first nine years. In this application the starting value of KS, at t=0, is irrelevant by 1947, because the series begins in 1929.

International technology transfers is approximated by a patent count (see section on data).

Applying the same methodology to the patent count series gave a lag of twelve to thirteen years and again a negatively skewed distribution. So, the patent knowledge stock is approximated in the profit function by a PIM with a depreciation rate of 8.3%, which is appropriate for a twelve year lag. The patent variable is the means of allowing 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.

For the non-international private sector, 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 the 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. However, due to these two factors, not all technical 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.

The lags on extension and education should be far shorter than that for R&D, so the same elaborate lag structures need not be imposed. The model selection criteria indicated that a single one period lag is the appropriate specification.

Lastly, since the technology variables are interdependent, the lags structures should be jointly estimated. Thus, the model selection criteria are applied to combinations of lags for the different variables in a grid search for the model that performs best.

3. THE MODEL

Assuming that farmers maximise expected profits, the normalised restricted profit function (Lau, 1976), with the conditioning factors included as fixed inputs,[4] is used to model farmer behaviour. Consider a multiple output technology producing outputs $Y(y_1,..,y_m)$, with the respective expected output prices $P(p_1,..,p_m)$, using n variable inputs $X(x_1,..,x_n)$ with prices $W(w_1,..,w_n)$. Variable expected profits are defined as:

$$\pi = \sum_{i=1}^{m} p_i y_i - \sum_{j=1}^{n} w_j x_j = P'Y - W'X \qquad (2)$$

Normalising the profit function with respect to an output or input price (w_0 in equation (2), which is the price of livestock inputs) has the practical advantages of ensuring that the homogeneity requirement is met, reducing the number of parameters to be estimated, formulates the problem in a manner consistent with economic theory and negating the need for deflating prices. The optimal solutions to maximising (1) would be equivalent to those obtained from the maximisation of the normalised restricted profits and thus the normalised expected profit function can be represented as:

$$\Pi^* = \Pi^*\left(\frac{P}{w_0}, \frac{W}{w_0}; Z, \theta\right) = \frac{\pi^*(P, W; Z, \theta)}{w_0} \qquad (3)$$

where capital pi represents the normalised restricted profit function, Z is the vector of fixed and quasi-fixed inputs, Q is the vector of technology variables, or conditioning factors (also treated as quasi-fixed in equation (3)) and "*" indicates optimised levels. The theoretical restrictions suggested on (3) are that the normalised restricted profit function (hereafter called the profit function) is non decreasing in P, non increasing in W, linearly homogeneous in prices, twice continuously differentiable and convex in prices, and cancave in the quasi-fixed factors (Lau, 1976).

The functional form employed is the generalised quadratic (GQ). The GQ profit function is defined as:

$$\Pi = \alpha_0 + \alpha'\hat{P} + \delta'\Theta + \frac{1}{2}\hat{P}'\beta\hat{P} + \frac{1}{2}\Theta'\phi\Theta + \hat{P}'\gamma\Theta \qquad (4)$$

where P hat is the stacked vector of normalised output and non-numeraire input prices, (P,R)' and Q is the stacked vector of k quasi-fixed and l fixed and conditioning factors. The vector α ($\alpha_1,..,\alpha_{m+n-1}$) and matrices β (β_{ij}, i,j=1,..,m+n-1), f (f_{gh}, g,h=1,..,K+L) and g (g_{ig},i=1,..,m+n-1, g=1,..,k+l) contain the parameter coefficients to be estimated. The vector of parameters d is of particular interest as these are the shadow prices of the fixed factors and technology variables. Applying Hotelling's lemma, we derive the (short-run) optimal levels of output supply and input demand:

$$y^*_i = \alpha_i + \sum_{j=1}^{m} \beta_{ij} p_j + \sum_{j=m+1}^{m+n-1} \beta_{ij} w_j + \sum_{g=1}^{k+1} \gamma_{ig}\Theta_g, \quad i = 1,..,m \qquad (5)$$

$$-x^*_i = \alpha_i + \sum_{j=1}^{m} \beta_{ij} p_j + \sum_{j=m+1}^{m+n-1} \beta_{ij} w_j + \sum_{g=1}^{k+1} \gamma_{ig}\Theta_g, \quad i = m+1,..,m+n-1 \qquad (6)$$

The long-run profit function, in contrast, consists of only variable factors of production. Since factors such as machinery, land, and livestock inventory are assumed to be at long-run equilibrium levels, no quasi-fixed factors are represented in the profit function. The vector Q only contains conditioning factors such as weather and technology, that are always exogenously supplied. Prices of the inputs that were quasi-fixed factors in the short run are included in the vector w. Variable input demands for these factors are obtainable using Hotelling's Lemma, and are estimated jointly with other input demands and other supply equations.

The price elasticities are derived as logarithmic derivatives of the supply and derived demand equations with respect to prices (Lass, 1985; Khatri, et al., 1994a). Shadow values are given by the partial derivatives of the profit function (Diewert, 1974) with respect to the Q variables. The derived shadow values can be interpreted equivalently as the marginal change in profits for an increment in a particular element of Q or as the imputed rental value for an additional unit of that factor. Of particular interest are the shadow values of capital, land and research. The difference between the rental value and shadow value indicates whether the factor is over, under or optimally utilised. The shadow value of research can be used to derive the rate of return to research investment (Huffman, 1987).

4. DATA

The national farm-level production data for the period 1947-92 were obtained from several sources, largely RSA (1994), and are described in some detail in Thirtle, et al. (1993). For both the short and long-term profit function specifications, the three output aggregates are: Crops, Horticulture, and Livestock and Livestock Products.

For the short-term profit function, the variable inputs are Divisia aggregated into four groups: (1) Hired labour; (2) Machinery running costs (fuel, machinery repairs and other); (3) Intermediate inputs (fertiliser, other chemicals and packing material) and (4) Feed and dips. Vehicles and fixed capital in the form of buildings and other fixed improvements are assumed to be quasi-fixed, as are the stocks of animals. The total area of land in the commercial sector is included as a fixed input.

For the long-term specification, all inputs are variable. These were Divisia aggregated into the following groups: (1) Hired labour; (2) Machinery running costs (fuel, machinery repairs and other); (3) Intermediate inputs (fertilizer, chemicals, packing material, feed and dips); (4) Capital, particularly vehicles and other capital in the form of building and fixed improvements; (5) Livestock; and (6) Land Thirtle et al. (1993) build up a capital stock variable using investment data by making assumptions about the depreciation rate of capital. Ball recalculated this capital stock for South Africa using depreciation rates similar to those assumed for U.S. agriculture using the method established in Ball (1985).[5] He also recalculated the rental price of capital, an output of the short run model, using Jorgenson's formula to derive a long-run capital service price from the assumed depreciation rate.

The other conditioning factors, that are treated as fixed inputs in both the short and long-term specifications, are public research expenditures, public extension expenditures, a rainfall index, world patents[6] and a farmer education index.[7] The construction of knowledge stock variables for these items were already outlined above. The expected prices are taken to be the previous year's actual prices (i.e. naive price expectations).[8]

5. RESULTS

There are too many parameters in the short run profit function (3) to estimate the full model in one stage, so the residual profit function approach (Bouchet, et al.,1989; Khatri, et al., 1994a) is used. The system of supply and demand equations (4) and (5) are estimated in the first stage and then the remaining variables are used to explain the residual. The estimated shadow prices and the input biases involve both the parameters from the supply and demand system and the residual profit function. However, as the majority of the parameters for the shadow price and input bias equations are in the supply and demand system, the parameters used in the residual profit function can be treated as constants (most of which are significant). This allows for the derivation of *indicative* significance bounds for the shadow price and input bias estimates.

The system of output supply and variable input demand equations are estimated using the iterative Zellner procedure. The system, with symmetry imposed, produces a large set of parameter estimates (not reported here), most of which are significant at the 5% confidence level. The coefficients of determination (R^2s) of the estimated supply and demand system equations (for both the short-run and long-run specifications) vary between 0.87 and 0.99 which is high, even for a time series model. The Durbin-Watson statistics indicate that there are no problems of serial correlation in the individual equations. Further, although homogeneity remains a maintained assumption (implicitly imposed when normalising), symmetry and monotonicity, which are necessary conditions for global convexity, are both satisfied by the estimated systems. The estimated profit functions are thus found to be acceptable both with

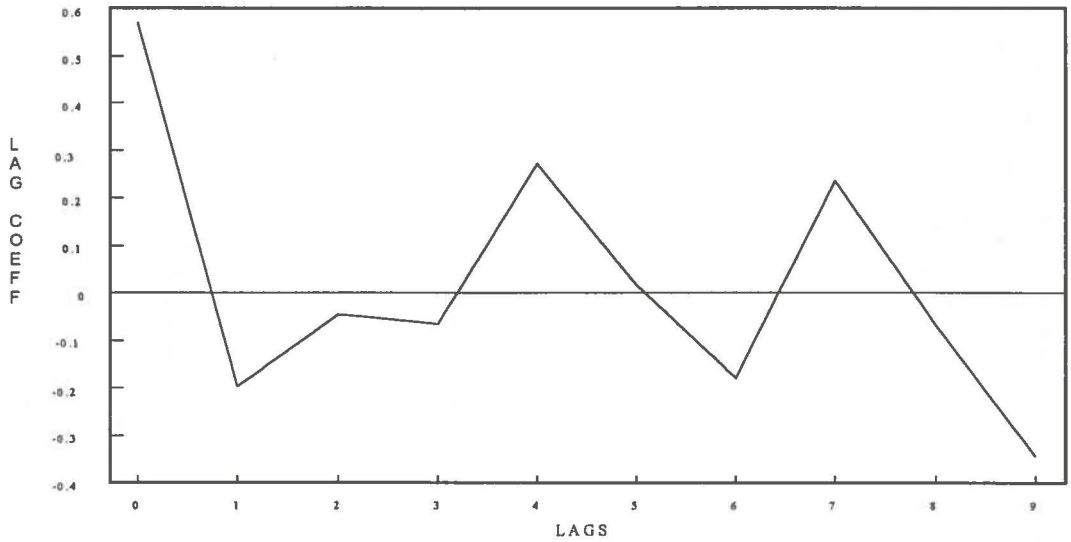

Figure 1: Unrestricted lagged round (9 years)

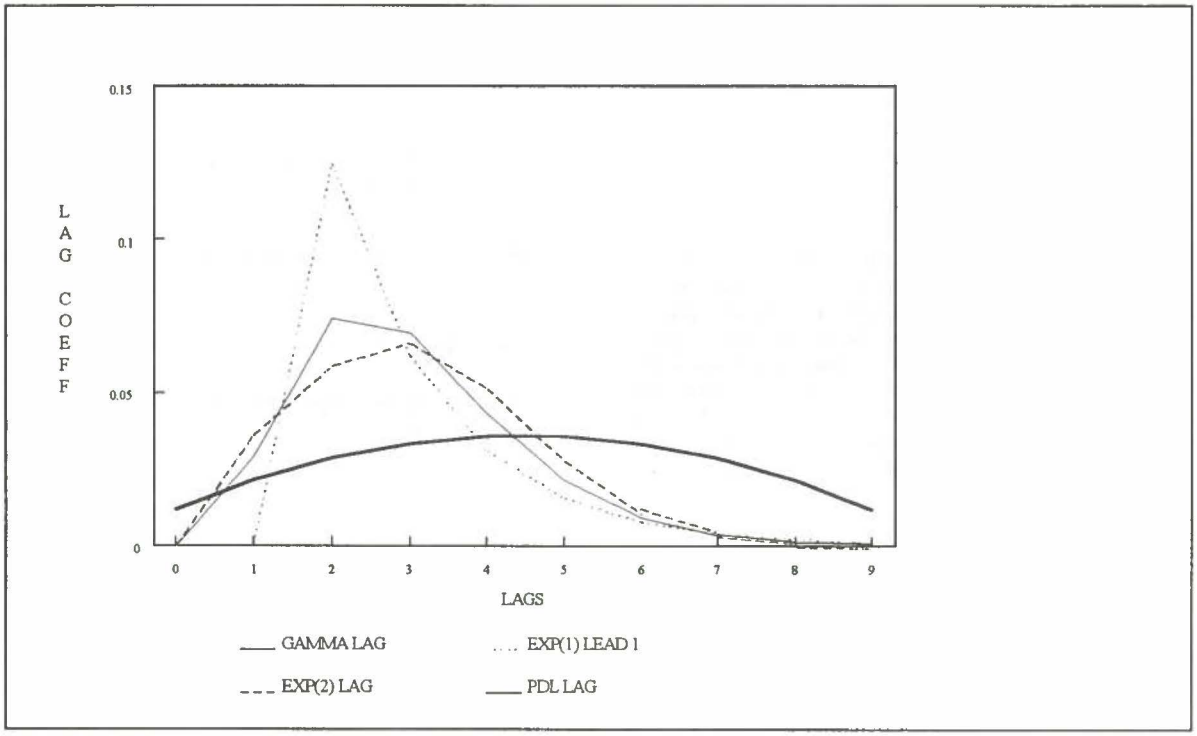

Figure 2: Lagged effects of research on productivity

respect to their statistical performance and theoretical consistency.

The results obtained with the short-run and long-run profit functions (that can be estimated in one stage) specifically the elasticity estimates, are in accordance with expectations. The elasticities of the outputs and variable inputs in the estimation obtained with the long-run approach and the short-run estimations are remarkably similar. As expected, the long-run elasticities for land, capital and livestock are consistently higher than the short-run elasticities. It can therefore be concluded that the results from both the short and long-run models are consistent.

The relative lack of supply response of South African agriculture, even over the long-run, is striking. This result corresponds very closely with the findings of Van Zyl (1986) and Sartorius von Bach and Van Zyl (1991). It also confirms earlier opinions on the abnormal development path for South African agriculture.[9]

Shadow Prices

The change in the profit function with respect to the technology variables represents their shadow values, that is, shadow values of technology factors are given by the partial derivatives of the profit function (Diewert, 1974) with respect to the technology variables. The derived shadow values can be interpreted equivalently as the marginal change in profits for an increment in a particular element of technology. This shadow value for R&D can be used to derive the rate of return to research investment (see Khatri, et al., 1996). Note, however, that the shadow values of the short and long-run conditioning variables are not directly comparable due to differences in the units of measurement for the capital items. These shadow values are reported in Table 1 for both the short and long-run specifications, at the variable means.

The extension and education variables have negative shadow values, indicating that these variables, on the margin, are of no use to producers. In contrast, international research spillovers (PATENTS) and public R&D expenditure (RES) have relatively high positive shadow values, indicating that expansion of these factors is likely to benefit South African agriculture.

The shadow price for public research was negative at the beginning of the period, after which the value has risen at an increasing rate, suggesting that the public research system is now making a considerable contribution to profitability (see Van Zyl, et al., 1993). The shadow price of the international knowledge stock (representing spillovers) indicates spillovers significantly affect productivity and profitability. The shadow price of extension is surprisingly small (although highly significant) in the short-run formulation, implying a near zero return on public extension expenditure. While in the long-run formulation, the shadow price of extension is substantially negative. The shadow price of extension has been falling over the period, which suggests that South African commercial farmers have become less dependent on public extension advice. This corresponds with the findings of Koch, et al. (1991), who show that government extension officers spend increasingly more time on administrative duties and do very little actual extension work.

As with extension, the education index appears to have considerable explanatory power in the model, judging by the significance levels of the education related coefficients. This results in a highly significant, but unexpectedly negative shadow price for education. The education index is a proxy for the farmer's managerial ability and thus we would certainly expect a positive shadow price for education. There is a strong indication from the fixed factor elasticities[10] that education augments output but also augments input use (more than proportionately in the case of non-labour inputs). As the education level of South African commercial farmers is relatively high, it is entirely possible that the minimum level required to assimilate research and extension messages has been surpassed. The shadow value of education was positive until the early 1960s, but has become increasingly negative since then.

An additional explanation of this phenomenon is found in the South African literature. Several authors illustrate how crop production has expanded into climatically marginal and more risky areas, and how especially intermediate input use and mechanisation have increased considerably in the period 1965 to the early 1980s (Van Zyl, et al., 1995). For example, over-mechanization was the order of the day (Van Zyl, et al., 1987), and particularly fertilizer was often applied up to levels where it actually decreased output (Korentajer, et al., 1990). This was especially disastrous given the bad climatic conditions of the early and late 1980s (Van Rensburg and Groenewald, 1987). Sartorius von Bach, et al., (1992) clearly show that it was the better educated farmers who adopted these practices to a greater extent, partly because maximum physical production--as opposed to maximizing profit--was the major goal and focus of the agricultural research effort.

Internal rate of return

The shadow prices for R&D reported above can be used to calculate the marginal rate of return to investment on domestic research expenditure. The internal rate of return (r) is calculated using the formula from Ito (1991)

$$\exp(r, L) = \int_0^{\infty} \left(\frac{\partial F}{\partial (RKS)}\right) \exp(-rt)dt \qquad (7)$$

where L is the average lag value for R&D, which is taken to be five years. The calculation reduces to

$$r e^{5r} = VMP_{RKS} \qquad (8)$$

where the Value Marginal Product of the research stock is the shadow price of research.

An interesting question arises from the comparison of the returns to research expenditure calculations using the short and long-run approaches. The long-run approach yields a MIRR that is considerably higher than that obtained with the short-run profit function of Khatri, et al. (1996). How much higher depends on the length of the lag between R&D expenditures and changes in TFP. In the short run, the lag is assumed to be 5 years, which is only appropriate in the long-run for R&D on variable inputs like seed varieties. The implied rates of return are 113% as compared with 44%, respectively. R&D on fixed or quasi-fixed inputs like irrigation equipment, cultivation implements and other specialized machinery takes longer than 5 years to have an effect. Khatri, et al. (1994c) show that the capital stock

Table 1: Estimated Shadow Values of the Conditioning Variables (Evaluated at the Variable Means)

Factor	Short-term Specification	Long-term Specification
Public Research	4.04	323.5
International Patents	0.23	342.8
Public Extension	-0.012	-290.6
Farmer Education	-1,378.5	-6,867.2

Note: All the shadow prices are significant at the 0.05 level.

takes 11 years to adjust, indicating an 11 year lag between R&D and TFP growth. The longer lag lowers the long-run MIRR to 58%. The correct rate of return is some unknown weighted average of the lags between R&D items that provide quick impacts, like improvements in seed varieties, and those that take longer to have an impact. The long-run rate is bounded by 113 and 58%, a range that exceeds the short run return.

These are certainly respectable rates of return on public expenditure. There are, however, the usual arguments that this figure may be somewhat diminished if we adjust for the dead-weight losses associated with tax collection (the means of financing public expenditure) and the possibility that public funding may be crowding out private sector research. The major point of interest, however, is the large difference between these rates when measured over the short and the long term.

6. CONCLUSION

Use of a long-run profit function has been shown to provide accurate estimates of returns to agricultural R&D in Europe and North America, a result that is tied to the long term basic and applied nature of the research institutions in these areas. Basic research into plant physiology and development takes place before plant breeders use the information to create new varieties with desirable characteristics. An additional lag occurs before outputs increase as the new seed varieties are diffused among farmers (see Khatri, 1994).

Agricultural R&D in South Africa is fundamentally different with a more adaptive character, and a shorter lag of five years for variable factors (see Thirtle and Van Zyl, 1994; 1996). The lag from basic to applied research is short cut in South Africa by making slight adjustments to seed varieties developed for similar environmental conditions in the northern hemisphere. Even when the fact is taken into account that some capital stock items take longer than five years to be impacted by R&D (by assuming that all of the capital stock adjusts more slowly) the result is a range of long-run returns that is greater than the short-run return. In this situation, the long-run profit function input demand and output supply elasticities are too high resulting in overestimation of returns to R&D.

A possible solution to this problem is to employ a short-run profit function in the calculation of returns to R&D. Several other inputs are held fixed and the result is a short-run return to R&D in South Africa that compares favourably with long-run return levels that have been established for the northern hemisphere.

NOTES:

1. There is a huge volume of literature on the returns to agricultural research. See, for example, Echeverria (1990) and Thirtle and Bottomley (1992).

2. Thirtle and Van Zyl (1994) used the two-stage decomposition approach to determine the returns to R&D and extension in South Africa and it is used here to predetermine the length and shape of the lags for the technology variables. These are then imposed in estimating the profit function, the results of which show that technical change is not Hicks neutral. This violates the assumptions implicit to the two-stage approach, which may give biased results.

3. This is despite the fact that government-funded research in the universities is included. We estimate that this accounts for about 75% of the agricultural research undertaken by the tertiary sector.

4. Many production function studies using time series data employ a time trend as an index of technology. Although common practice, Clark and Youngblood (1992) demonstrate the erroneous resultant specification implied by the use of a deterministic time trend with different stationary production and price data. By including the (productivity shifting) conditioning factors directly in the objective function their criticism is addressed in a manner consistent with their recommendations. Quasi-fixed factors (capital stocks) are those that are fixed in the short-run (one production period), but can be varied in the longer-run. Fixed inputs and conditioning variables, including public and private research expenditure, international stock of knowledge, extension, farmer education and weather, are factors of production that cannot be varied by the farmer even in the long-run. Thus, profit maximisation is assumed to be subject to levels of these factors.

5. We are grateful to Eldon Ball of the ERS (USDA) for pointing out the necessity of converting capital stocks into capital flows for the long-run.

6. The patent data comes from the US patent database compiled at the University of Reading by John Cantwell. The series are patent counts, for all agriculture-related chemical and mechanical patents registered in the United States.

7. The farmer education index (ED) is the average number of years of secondary education of farmers, which was kindly provided by the South African Agricultural Union (SAAU). The set of conditioning factors can be shown to Granger cause changes in TFP (Khatri, et al., 1994b).

8. This is in accordance with the findings of Van Schalkwyk, et al. (1994), who concluded that naive price expectations best explain aggregate South African farmer behavior from among a number of different expectation regimes.

9. For a summary, see World Bank (1994), Thirtle, et al. (1993) and Kirsten and Van Zyl (1996).

10. Although not reported, all input and output elasticities with respect to education are positive, and all but one of these elasticities are highly significant.

REFERENCES

BALL, V.E. (1985). "Output, Input, and Productivity Measurement in U.S. Agriculture, 1948-79", American Journal of Agricultural Economics, 67(3):475-486.

BOUCHET, F.C., ORDEN, D. & NORTON, G.W. (1989). "Sources of Growth in French Agriculture", American Journal of Agricultural Economics, 71(2).

CLARK, J.S. & YOUNGBLOOD, C.E. (1992). "Estimated Duality Models with Biased Technical Change", American Journal of Agricultural Economics, 72(2):353-360.

DIEWERT, W.E., (1974). "Applications of Duality Theory", in M.D. Intriligator and D.A. Kendrick (eds.), Frontiers of Quantitative Economics: Volume 2, North-Holland Publishing Company, Amsterdam.

ECHEVERRIA, R. (1990). (ed.) Methods for Diagnosing Research System Constraints and Assessing the Impact of Agricultural Research. ISNAR, The Hague.

EVENSON, R.E, LANDAU, D. & BALLOU, D. (1987). "Agricultural Productivity Measures for US States", Proceedings of a Symposium, Atlanta, Georgia, Jan.29-30, 1987, Miscellaneous Publication 52-1987, Minnesota. Agricultural Experiment Station, University of Minnesota, St.Paul, MN.

GEWEKE, J. & MEESE, R. (1981). "Estimating Regression Models of Finite but Unknown Order", International. Economic Review, 20:203-216.

GRILICHES, Z. (1979). "Issues in Assessing the Contribution of R&D to Productivity Growth", The Bell Journal of Economics, Spring, 10(1): 92-116.

HUFFMAN, W.E. (1987). "Research Bias Effects for Input-Output Decisions: An Application to U.S. Cash-Grain Farms", Proceedings of a Symposium, Atlanta, Georgia, Jan.29-30, 1987, Miscellaneous Publication 52-1987, Agricultural Experiment Station, University of Minnesota, St. Paul, Minnesota.

ITO, J. (1991). "Assessing the Returns of R&D Expenditures on Post-War Japanese Agricultural Production", Research Paper No. 7, National Research Institute of Agricultural Economics, Ministry of Agriculture, Forestry and Fisheries, Tokyo.

KHATRI, Y.J. (1994). Technical Change and the Returns to Research in UK Agriculture, 1953-1990, Ph.D. Dissertation, University of Reading, England.

KHATRI, Y.J., JAYNE, T. & THIRTLE, C. (1994a). "A Profit Function Approach to the Efficiency Aspect of Land Reform in Zimbabwe", XXI IAAE International Conference, Harare, Zimbabwe, August 1994.

KHATRI, Y.J., THIRTLE, C. & VAN ZYL, J. (1994b). The Rate of Return to Agricultural Research in South Africa: The Two-Stage Approach, mimeo, University of Pretoria, South Africa.

KHATRI, Y.J., THIRTLE, C. & VAN ZYL, J. (1994c). "South African Agricultural Competitiveness: A Profit Function Approach to the Effects of Policies and Technology", XXI IAAE International Conference, Harare, Zimbabwe, August 1994.

KHATRI, Y.J., THIRTLE, C. & VAN ZYL, J., (1996). "Public R&D as a Souce of Produvtivity Change in South African Agriculture", SA Journal of Science, 92:143-150.

KIRSTEN, J.F. & VAN ZYL J., (1996). "The Contemporary Policy Environment: Undoing the Legacy of the Past", in J. van Zyl, J.F. Kirsten and H.P. Binswanger (eds.), Policies, Markets and Mechanisms for Agricultural Land Reform in South Africa, Oxford University Press, Cape Town.

KISLEV, Y. & PETERSON, W.L, (1982). "Prices, Technology and Farm Size", Journal of Political Economy, 90:578-595.

KOCH, B.H., VAN ZYL, J. & VAN DER WATEREN, J.J. (1991). "The Role of Extension in the Development of the Farmer as Entrepreneur", Development Southern Africa, 8(1):127-136.

KORENTAJER, L., BERLINER, P.R., DIJKHUIS, F.J. & VAN ZYL, J. (1989). "Use of Climatic Data for Estimating Nitrogen Fertilizer Requirements of Dryland Wheat", Journal of Agricultural Science, 113:131-137.

LASS, D.A., (1985). Estimation of Total Factor Productivity Growth in the Corn Belt Region: A Dual Approach to Measurement, Ph.D. Thesis, Pennsylvania State University.

LAU, L.J. (1976). "A Characterisation of the Normalised Restricted Profit Function", Journal of Economic Theory, 12(1).

RSA, (1994). Abstract of Agricultural Statistics 1994, Directorate of Agricultural Economic Trends, Department of Agriculture, Pretoria, South Africa.

SARTORIUS VON BACH, H.J. & VAN ZYL, J. (1991). "Have recent Structural Changes Caused Agriculture to Become Less Rigid?" Development Southern Africa, 8(3): 399-404.

SARTORIUS VON BACH, H.J., VAN ZYL, J. & KOCH, B.H. (1992). "Managerial Ability and Problem Perceptions: A Case Study of Economic Survival and Failure in Mixed Dryland Farming", South African Journal of Agricultural Extension, 22:13-18.

SCHMIDT, P. (1974). "An Argument for the Usefulness of the Gamma Distributed Lag Model", International Economic Review, 15: 246-250.

THIRTLE, C. & BOTTOMLEY, P. (1992). "Total Factor Productivity in UK Agriculture, 1967-90", Journal of Agricultural Economics, 43(3):381-400.

THIRTLE, C., SARTORIUS VON BACH, H. & VAN ZYL, J. (1993). "Total Factor Productivity in South African Agriculture, 1947-91", Development Southern Africa, 10(3):301-317.

THIRTLE, C. & VAN ZYL, J. (1994). "Explaining TFP Growth in South Africa: The Returns to R&D and Extension", South African Journal of Agricultural Extension, 23.

THIRTLE, C. & VAN ZYL, J. (1996). "Measuring Returns to R&D in South Africa". Unpublished paper read at a SACCAR/ARC workshop, Silverton.

TSURUMI, H. (1971). "A Note on Gamma Distributed Lags", International Economic Review, 12: 317-323.

VAN RENSBURG, B.J. & GROENEWALD, J.A. (1987). "The Distribution of Financial Results and

Financial Ratios Among Farmers During a Period of Financial Setbacks: Grain Farmers in Western Transvaal, 1981/82", Agrekon 26(1).

VAN SCHALKWYK, H.D., VAN ZYL, J., VAN ROOYEN, C.J. & KIRSTEN, J.F. (1994). "The Agricultural Land Market in South Africa: Options for Land Reform", Paper presented at the XXI IAAE International Conference, Harare, Zimbabwe, August 1994.

VAN ZYL,, J. (1986). "Elasticity of Factor Substitution II: An Empirical Application", Agrekon, 25(3).

VAN ZYL, J., FÉNYES, T.I. & VINK, N. (1987). "Labour-related Structural Trends in South African Maize Production", Agricultural Economics, 1(3):241-258.

VAN ZYL, J., MCKENZIE, C.C. & KIRSTEN, J.F. (1995). "Natural Resource Issues in Rural South Africa", in J. van Zyl, J.F. Kirsten and H.P. Binswanger (eds.), Policies, Markets and Mechanisms for Agricultural Land Reform in South Africa, Oxford University Press, Cape Town.

VAN ZYL, J., VAN SCHALKWYK, H.D. & THIRTLE, C. (1993). "Entrepreneurship and the Bottom Line: How Much of Agriculture's Profits is Due to Changes in Price, How Much to Productivity?", Agrekon, 32(4):223-229.

WORLD BANK. (1994). "South African Agriculture: Structure, Performance and Options for the Future", Discussion Paper on Aspects of the Economy of South Africa No. 6, Southern Africa Department, World Bank, Washington, D.C.