THE RATE OF RETURN ON EXPENDITURES OF THE SOUTH AFRICAN AGRICULTURAL RESEARCH COUNCIL (ARC)

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All the rate of return estimates, regardless of methodology or the level of aggregation, are entirely consistent and logical. The returns show that the ARC has been extremely successful economically and has followed a sound strategy of exploiting spillovers from foreign R&D systems. However, there must be a strong socio-economic component to the ARC's efforts if it is to reach the disadvantaged.

1. INTRODUCTION: RATE OF RETURN (ROR) STUDIES

In a situation of increasing accountability and competition for public funding in South Africa, the ARC has to be able to show that its use of public money and both appropriate and effective. Previous studies (Khatri, Thirtle & van Zyl, 1996) have shown that the ROR to public sector agricultural R&D in South Africa is over forty percent. This collection of disaggregated studies estimate rates of return at the institute, crop and project level. This is necessary because knowing that the ROR to public R&D is high has the single policy implication that there has been under-investment. The more difficult issues of priority setting and the allocation of research investments between and within the crop, horticulture and animal enterprises, and between scientific areas like agronomy, plant protection, animal health and biotechnology all need to be studied at lower levels of aggregation.

This presents problems because the allocation of some inputs between activities is usually not known. At the national level it is possible to explain total output using all the inputs that enter the agricultural production process. The total factor productivity and profit function approaches are preferred at this level. But, measuring TFP is not possible at the crop level, so it is often necessary to resort to partial productivity measures such as yields. The alternative is supply response functions, which have the advantage of using input prices (rather than quantities) as independent variables and these are not crop-specific. The

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inclusion of R&D expenditures, to account for shifts in the supply curve, generates an elasticity and thus makes ROR calculations possible.

The returns to the ARC's R&D have been substantial. However, understanding and explaining the history of agricultural research is the first step on the road to improving its socio-economic impact. This review shows that policy conclusions follow from the analysis. The poverty focus that has been lacking requires that research resources are reallocated to crops with smallholder, nutritional and employment potential. The scientific difficulties may be as great as the socio-economic challenges, in the current situation, as global warming presents special difficulties for all the SADC countries. They will need the help of the most advanced aspects of science that the ARC can offer, such as the application of biotechnology. This research has shown that South Africa has a research system that is sufficiently advanced to capture international spillovers of scientific knowledge and technology, especially from the USA and the UK. It can function as the conduit for transferring these gains to the other SADC countries and beyond, thus helping to take African agriculture into the world system. Without these efforts, the prospects for agricultural growth in SADC and its neighbours are limited and Africa will continue to fall behind the rest of the world in incomes, nutrition and prospects.

2. A PRELIMINARY VIEW: CONGRUENCE BETWEEN EXPENDITURES AND VALUES

Congruence has been commonly used as a crude first step in examining the allocation of resources to research. All else being equal, the expectation is the funds are allocated to equate research intensities (the ratio of research investment to the value of output). The advantage of this approach is that it requires minimal information and can be used to compare resource allocations to research by factor, by production stage, by region, and among disciplines. However, congruence considers only the demand side and ignores all differences in probabilities of payoffs to research investment. Thus, the supply side is missing and there is a need to include likely adoption rates, probability of success or likely research-induced productivity gains.

The simplest approach is to compare the ratios of the percentage of expenditures to the percentage of the value of output, across crops and other enterprises. Perfect congruence between the value shares and research expenditure shares gives coefficients equal to unity. The congruency indices calculated for the crops serviced by each institute are shown in Table 1. The results suggest that research allocations have been quite remarkably consistent with the value of the commodities. The indices for the grain crops, small grains and livestock suggest that they are relatively under-funded, whereas fruit, wine, tobacco and cotton have been favoured. However, the deviations are small relative to the sources of error. For instance, poultry form a significant proportion of the livestock value and could be excluded since poultry R&D is conducted by the private sector.

Table 1: Congruence between crop values and research expenditures

Commodity	Research Institute	Congruency Index
Grain Crops[1]	Grain Crops Institute	0.90
Small Grains[2]	Small Grains Institute	0.98
Tobacco and Cotton	Tobacco and Cotton Institute	1.04
All livestock	All Livestock Institutes	0.96
Deciduous fruit[3]	Infuitec	1.02
Vegetables and ornamental plants	Roodeplaat	1.01
Tropical and sub tropical crops[4]	Institute for Tropical and Subtropical Fruit	1.05
Grapes	Nietvoorbij	1.04

1 These include maize, sorghum, dry beans, groundnuts, sunflower seed, soya beans
2 These include wheat, oats, barley, rye
3 This includes all deciduous fruit, dried fruit and nuts i.e: apples, pears, peaches, nectarines, plums, apricots, berries.
4 This includes all tropical and sub-tropical crops such as avocados, bananas, mangoes, litchis and citrus.

3. METHODOLOGIES USED IN THE RATE OF RETURN CALCULATIONS

The studies on which this review is based use a variety of approaches to explain output and productivity changes. First, Thirtle, von Bach & van Zyl (1993) used simple index number techniques to construct an index of total factor productivity (TFP) for South African agriculture. Explaining TFP, in this two-stage approach, with R&D, extension, patents, farmer education and the weather leads to estimates of the returns to investments in agricultural research and extension. Then, the dual profit function (Khatri, Thirtle & van Zyl, 1996) was extended to incorporate the inputs that generate technical change. R&D and other explanatory variables are incorporated into output supply and input demand functions, which we estimated as a simultaneous system, in a single stage. This integrated approach also allows the estimation of separate rates of return for crops, horticulture and livestock (van Zyl, 1996).

This completes the aggregate analysis, for which the basic approaches, lag types and lengths, RORs and references are reported at the top of Table 2 in the next section. The ROR results are related to the structure of the ARC, which is also in the next section. The rest of the Table shows the results for the lower level studies. These begin with field crops. The grains covered are maize, sorghum, wheat; oilseeds are represented by groundnuts; roots and tubers by sweet potatoes and speciality crops by tobacco. The horticulture and fruit sector is represented by wine grapes, bananas, deciduous fruit, lachenalia and protea. Lastly, for the animal sector, animal health is separated from animal improvements and range and forage research (Townsend & Thirtle, 1998).

These estimates of returns at the institute, crop and project levels are derived using two approaches. First, the production function approach can be retained, but with yields instead of TFP. Yield changes are explained by changes in the use of inputs (Xi), such as fertilizer, R&D and the weather,

$$\mathrm{Ln(YIELD)}_t = \beta_0 + \sum_{i=1}^{m} \beta_i \mathrm{Ln}(X_i)_t + \sum_{j=0}^{n} \beta_j \mathrm{Ln(RD)}_{t-j} + W_t \qquad (1)$$

where all the variables, except the weather are in logarithms, so that the coefficients are elasticities and the effects of R&D expenditures are lagged by up to n years. The supply response function is the alternative, in which output is a function of own price, the price of substitutes and compliments, input

$$Q_j = f\,(P_j, P_r, X_i, I, RE, W) \qquad (1)$$

prices, technology, the environment, institutional factors and the weather. Thus, the supply function for the general case is expressed as where Qj is the quantity of output of good j supplied, Pj is the price of output j, Pr is the price of related or competing outputs, the Xis are inputs, RE is real research (and extension, if available) expenditures, I is infrastructure variables, such as irrigation and W is a rainfall index, which represents the weather. Considerable judgement, based on local knowledge, is required to select the variables that matter.

In the model outlined above it is implicitly assumed that the suppliers will have reached an equilibrium position in response to known current prices. Since the farmer will tend to be in a state of disequilibrium, adjusting to changing prices and other condition, partial adjustment is assumed

$$Q_t - Q_{t-1} = (Q_t^* - Q_{t-1}) \tag{2}$$

where the actual change in the level of output in period t, Qt - Qt-1, will depend on the gap between the target value, Qt*, and the actual value of the last period, Qt-1. Thus, the coefficient ß is the adjustment elasticity. Allowing also for price expectations and slow response to price changes for the tree crops leads to Nerlove (1958) type models in which both lagged output and output prices appear as independent variables.

$$q_{ht} = \beta_0 + \sum_{i=0}^{m} \beta_i \, p_{h_{t-i}} + \sum_{j=m+1}^{n} \beta_j \, q_{h_{t-j}} + \sum_{k=n=1}^{s} \beta_k \, p_k + \sum_{i=0}^{n} \alpha_1 \, rd_{t-i} + W_t \tag{3}$$

where the lower case letters indicate logarithms, so that the coefficients are elasticities. The logged prices of substitutes, complements and inputs are all included in ph and rd is also logged and lagged.

A further extension is the separate estimation of yields and area harvested, since output responses depend on both changes in the area planted and changes in the yield per unit of area. Thus, the output response is decomposed into these two components and the two equations are estimated together. The menu of possible explanatory variables remains the same and it is to be expected that the impact of new technology will be stronger in the yield equation. In the final results reported, the area and yield relationship proved useful only for bananas.

In most of the disaggregated studies the model estimated is fairly basic, but for the grains, a more sophisticated error correction model was preferred (Townsend, Van Zyl & Thirtle, 1997). Indeed, the partial adjustment model is a restricted special case of the ECM, which uses first differenced variables (i.e stationary variables) and incorporates the correction mechanism by including deviations from the long run equilibrium. The ECM is a reparameterization of the autoregressive distributed lag model

$$\Delta q_t = \gamma_0 \Delta p_t - (1 - \alpha_1)[q_{t-1} - \beta_0 - \beta_1 p_{t-1}] + u_t \tag{4}$$

where γ_0 captures the short run effect on q of the changes in p. β_1 accounts for the long run equilibrium relationship between q and p. The term in the square brackets, qt-1 - β0 - βpt-1, is the divergence from the long run equilibrium, so that when equilibrium holds, this term is equal to zero. The term $(1 - \alpha_1)$ measures the extent of the correction of such errors by adjustment in y, so $(1 - \alpha_1)$ must be negative and less than one for the correction to be direction back towards equilibrium, as is required. As all the variables in the ECM are stationary, standard regression techniques are valid.

Regardless of the choice of model, determining the length and shape of the lag distribution is crucial if the rates of return are to be accurately estimated. The lag between research expenditures and financial returns depends on the types of R&D that the expenditures are used for, the nature of the enterprise, and the effective distribution of the product, which depends in part on the extension service. More basic activities, such as developing new cultivars used to take about 12 years for grain crops, although the gestation period has now fallen considerably with the use of techniques developed by the biotechnologists, such as gene splicing. At the other extreme, agronomic and management research can produce results in a year or so and be in use on a significant proportion of farms by the next year, especially if the researcher run their own well-targeted extension programme. However, the period between planting and maturity for the tree crops inevitably means that the research lag will be longer for these enterprises, as the results showed.

4. RATE OF RETURN RESULTS

The basic approaches, lag types and lengths, RORs and references for all the studies are reported in Table 2 and the ROR results are related to the structure of the ARC. First, the aggregate studies showed that the majority of TFP growth in South African commercial agriculture in the period 1947-91 was explained by public research and development (R&D) and extension expenditures, farmer education, and the weather. The gross return on investment in research is between 60% and 65%. For extension the results vary far more with the choice of model, from 62% to 162%. All else being equal, this suggests that there is under-investment in the generation and diffusion of agricultural technology.

The application of the integrated, single-stage approach by fitting a residual profit function, which incorporates the technology variables, produces short term and long run estimates of the output-supply and input-demand price elasticities, elasticities of the effects of relaxing the non-variable input constraints, and shadow prices for these non-variable factors. Local public sector agricultural research and international research spillovers are incorporated directly in the profit function. Shadow values of these conditioning factors are derived, providing measures of their implicit values in production. The shadow value of research is used to derive the marginal internal rate of return to public sector agricultural research (R&D), that is estimated to be between 44% and 53%. Since the profit function was estimated with three outputs, namely crops, horticulture and fruit and animals, the coefficients allow for separate rate of return (ROR) calculations for these enterprises. Thus, crops have a fairly average ROR of 30%, horticulture and fruit an unusually high rate of 100% and animals fare poorly with an ROR of only 5%.

The institute level results are entirely consistent with these figures, despite the differences in methodology. The wine and fruit institutes have high returns, from 40% to 78%, while the ROR on animal production improvements and range and forage research is far lower at 11% to 16%. In fact, this is one of the most encouraging outcomes, since almost all previous studies have suggested the research on extensive animal system yield extremely poor returns. Thus, the ARC appears to be faring better than any country previously investigated. The reason for this entirely acceptable result, instead of the 5% outcome, is simply that animal health expenditures were not included in the calculation, but were modelled separately. Thus, instead of assuming that there would be zero productivity growth if there were no research, the animal health expenditures, on both research and dipping were used to explain the decline in animal losses from 1920. This gave a ROR, in terms of the value of the animals saved, of at least 36%. This is the first time that the value of "maintenance" research has been quantified and represents an advance on the standard methodology.

At the crops level, the results are again entirely consistent with the outcomes at the higher level of aggregation. Maize and wheat are very close to the 30% figure, while sorghum appears to have been under-funded, which has been shown to be true for several other African countries. Groundnuts and tobacco have higher returns, while sweet potatoes is lower, probably due to the relatively difficulty of working with root crops, which is also well recorded. Tropical and sub-tropical fruit research contributes to the high ROR for the fruit and horticulture group.

At the project level, the Russian wheat aphid control programme has generated a rate of return rather higher than the ROR for aggregate wheat research and the cover crop management programme for wine grapes has a similar return to that for the institute. At the other extreme, the returns to research for ornamental flower is low, at 6.5% to 12% for lachanalia and 8% to 12% for

Table 2: Methods, Lags and Rates of Return for the ARC

Study & Period	Method	**Lag Model**	**Length Years**	**ROR %**	**Reference**
1) Aggregate 1955-91	TFP - 2 Stage	2nd Degree Polynomial	10	64	Thirtle, Von Bach & Van Zyl 1993
2) Aggregate 1947-91	Profit Function	PIM Capital Stock	5	44	Khatri, Thirtle & Van Zyl, 1996
3) Crops 1947-91	Profit Function	PIM Capital Stock	5	30	Van Zyl, 1996
3) Horticulture 1947-91	Profit Function	PIM Capital Stock	5	100	Van Zyl, 1996
3) Animals 1947-91	Profit Function	PIM Capital Stock	5	5	Van Zyl, 1996
Field Crops					
4) Maize 1950-95	ECM Output & Area & Yield Model	Polynomial 2, Gamma, Beta	8	29-39	Thirtle, Van Zyl and Vink, forthcoming
4) Wheat 1950-95	ECM of Supply & Yield Model	Polynomial 2, Gamma, Beta	10	28-34	Thirtle, Van Zyl & Vink, forthcoming
4) Sorghum 1950-95	ECM of Supply & Yield Model	Polynomial 2, Gamma , Beta	13	50-63	Thirtle, Van Zyl & Vink, forthcoming
5) Groundnuts 1968-95	Yield Changes due to ARC program	Single lag value	6	50	Thirtle, Townsend & Van Zyl, 1997
6) Tobacco, 1965-1995	Supply, Price Lags	2nd Degree Polynomial	16 lag 2 lead	50-53	Thirtle, Townsend & Van Zyl, 1997
7) Sweet Potatoes, 1952-94	Supply Response	2nd Degree Polynomial	22 lag 3 lead	21	Thirtle, Townsend & Van Zyl, 1997
8) Wheat Aphid Control	Economic Surplus	Ex Ante	NA	35-49	Marasas *et al*., 1997
Animals					
9) Animal Production, 1947-94	Distributed Lag Supply Response	2nd Degree Polynomial	13	11-16	Townsend & Thirtle, 1998
10) Animal Health, 1947-82	Production Function	2nd Degree Polynomial	15	Over 36	Townsend & Thirtle, 1998
Horticulture & Fruit					
11) Wine Grapes, 1987-96, 7 Regions	Yield Model Panel Data	2nd Degree Polynomial	7	40-60	Townsend & Van Zyl, 1997
12) Crop Cover Management, 1987-96	Yield & Residual	2nd Degree Polynomial	7	44	Thirtle, Townsend & Van Zyl, 1997
13) Bananas, 1953-95	Supply, Area & Yield	Gamma	16	50	Thirtle, Townsend & Van Zyl, 1997
14) Deciduous Fruit, 1965-94	Supply Response	2nd Degree Polynomial	18	78	Thirtle, Townsend & Van Zyl, 1997
15) Lachenalia	Economic Surplus	Ex Ante	NA	6.5-12	Niederwieser *et al*., 1997
16) Protea	Economic Surplus	Ex Ante	NA	8	Wessels *et al*. (1997)

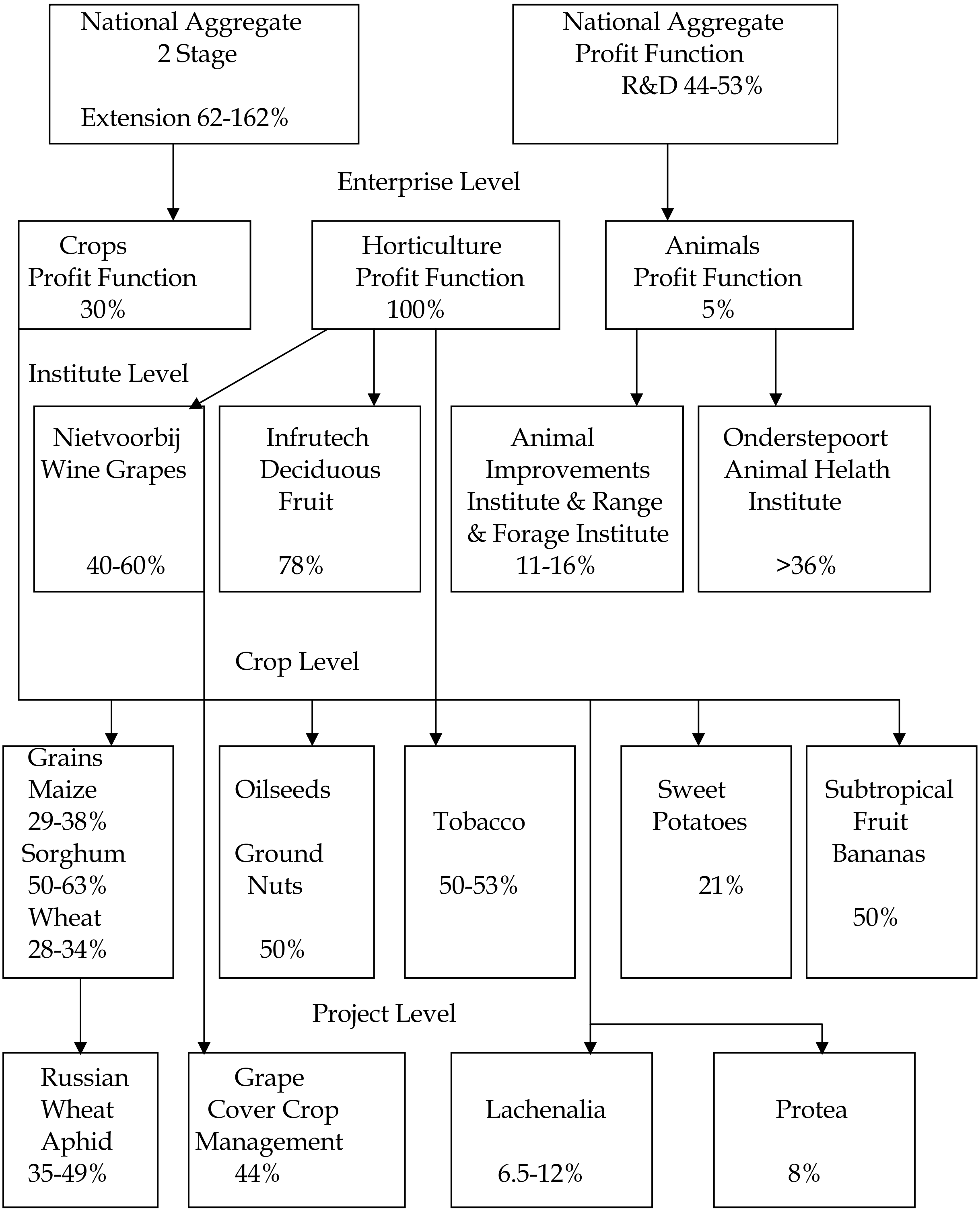

Figure 1: Disaggregating the returns to R&D

proteas. In both cases the problem is the gestation period, which led to slow results in the breeding programmes and even longer lags before financial benefits were generated by growers. These cases highlight the importance of the lag distributions, which were discussed above. Note that these studies were performed by ARC staff, rather than the authors of this paper. Thus, they do not follow the methods described in section 3, but they are reported here in order to give as complete a picture of the ARC's research as possible.

5. CONCLUSIONS

The results illustrate that there is no doubt that the ARC has been scientifically successful. The ability to maintain its position in the international system is evidence of this. All the rate of return estimates, regardless of methodology, are entirely consistent, so it is highly unlikely that the analysis is seriously faulty. The returns show that the ARC has been extremely successful economically and has followed a sound strategy of exploiting spillovers from foreign R&D systems.

However, there must be a strong socio-economic component to the ARC's efforts if it is to reach the most disadvantaged, which means not just generating adequate incomes for smallholders in the poorest rural areas, but also ensuring that the benefits include improving the nutritional standards of women and children. The ARC faces the huge challenge of reversing the mistakes of the past and ensuring a strong poverty focus in the future. This cannot be done by the ARC alone, as it is too far upstream in the technology generating process. Better articulation is essential, especially close collaboration with the Department of Agriculture and critically, the provincial agriculture departments, who current bear much of the responsibility for reaching the smallholders.

This means responding to the needs of farmers, rather than producing great science, although the two are not mutually exclusive. Crops with smallholder potential, such as groundnuts, which are also nutritionally valuable, should get high marks in scoring models used to allocate research resources. So should labour intensive crops, even tobacco, which is also relatively drought-resistant. Export crops score well too since the contribution of agricultural products to foreign exchange earnings is substantial.

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