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South African Agricultural Competitiveness: A Profit Function Approach to the Effects of Policies and Technology

INTRODUCTION

Of the 98 million hectares used for agriculture in South Africa, over 80 per cent is accounted for by commercial farms in white areas. The commercial sector in South Africa resembles that of any developed country and shares many of the problems of First World agriculture. Protection and policies such as overvalued exchange rates, subsidized agricultural credit, negative real interest rates and generous tax concessions on machinery purchases led to overcapitalization until the 1980s (Thirtle *et al.*, 1993). There are also problems of intensification such as the 'over-indulgence in the use of fertilizer' (Rensburg and Groenewald, 1987) and soil erosion, which is estimated to be occurring at more than 30 times the rate of soil formation (Huntley *et al.*, 1989). The subsistence sector (black farm families in the homelands) similarly resembles the kind of subsistence agriculture practised throughout Southern Africa. Kassier and Groenewald (1990) provide a perspective on the historical (post-colonial) developments including the legal and institutional frameworks resulting in the current dual structure of South African agriculture.

With the recent non-racial democratization of South Africa, agricultural policy will be a focus of attention. Food security and foreign exchange requirements highlight the need for continued increases in efficiency and international competitiveness in the agricultural sector, while equity considerations make land reform essential.

The objectives of this paper are to identify the sources of productivity growth in the commercial sector and particularly the effectiveness of domestic agricultural research policy. A full range of price elasticities are estimated, for the outputs and variable inputs, since information on price responsiveness is useful for policy purposes. For the fixed factors and capital items, shadow prices are calculated, which give indications of the effects of macro policy on the farm sector, which is assumed to be attempting to maximize expected profits.

The normalized dual profit function model is described in the next section, which is followed by brief discussion of the data. The main part of the paper

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then reports the results, beginning with price and fixed factor elasticities. These are followed by estimates of the shadow prices of the fixed factors, which are discussed in some detail, since there is evidence both of the pay-offs to investment in agricultural R&D and of the costs of the distortionary macro-economic and social policies that have marred the recent history of South Africa. The results are completed by estimates of the factor-saving biases of technical change. There is a brief concluding section.

THE MODEL

There are essentially two approaches to explaining sectoral productivity change. 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 minimizing 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.

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

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

Normalizing the profit function with respect to an output or input price has the practical advantages of ensuring that the homegeneity requirement is met and of reducing the number of parameters to be estimated. The optimal solutions to maximizing (1) would be equivalent to those obtained from the maximization of the normalized restricted profits and thus the normalized expected profit function can be represented as:

$$\Pi^* = \Pi^*\left(\frac{P}{w_O}, \frac{W}{w_O}; Z, \theta\right) = \frac{\pi^*(P, W; Z, \theta)}{w_O} \tag{2}$$

where Π represents the normalized restricted profit function and * indicates optimized levels. The theoretical restrictions suggested in (3) are that the normalized 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 (Lau, 1976).

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

$$\Pi = \alpha_0 + \alpha'\hat{P} + \delta/\theta + \frac{1}{2}\hat{P}'\beta\hat{P} + \frac{1}{2}\theta'\phi\theta + \hat{P}'\gamma\theta \tag{3}$$

where $\hat{P}$ is the stacked vector of normalized output and non-numeraire input prices, (P,R), and θ is the stacked vector of k quasi-fixed and l fixed and conditioning factors. The vector α $(\alpha_1,\ldots,\alpha_{m+n-1})$ and matrices β $(\beta_{ij}, i,j=1,\ldots, m+n-1)$, ϕ $(\phi_{gh}, g,h=1,\ldots,K+l)$ and γ $(\gamma_{ig}, i=1,\ldots,m+n-1,\ g=1,\ldots,k+1)$ contain the parameter coefficients to be estimated. Applying Hotelling's lemma, we derive the (short-run) optimal levels of output supply and input demand:

$$y_i^* = \alpha_i + \sum_{j=1}^{m}\beta_{ij}p_j + \sum_{j=m+1}^{m+n-1}\beta_{ij}w_j + \sum_{g=1}^{k+1}\gamma_{ig}\theta_g, \quad i=1,\ldots,m \tag{4}$$

$$-x_i^* = \alpha_i + \sum_{j=1}^{m}\beta_{ij}p_j + \sum_{j=m+1}^{m+n-1}\beta_{ij}w_j + \sum_{g=1}^{k+1}\gamma_{ig}\theta_g, \quad i=m+1,\ldots,m+n-1 \tag{5}$$

The price elasticities are derived as logarithmic derivatives of the supply and derived demand equations with respect to prices. If the elements of θ are viewed as short-run constraints on production, it is possible to derive the effects of relaxing the θ variable constraints, on the output and variable input levels. These 'fixed factor elasticities' are derived as logarithmic derivatives of the supply and derived demand equations with respect to the elements of θ (Lass, 1985; Khatri, 1994).

Shadow values are given by the partial derivatives of the profit function (Diewert, 1974) with respect to the θ variables. The derived shadow values can be interpreted equivalently as the marginal change in profits for an increment in a particular element of θ 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 utilized. The shadow value of research can be used to derive the rate of return to research investment (Huffman, 1987). Dual measures of technological bias can be obtained from the profit function. Huffman (1987) suggests a summary measure which provides input and output biases with respect to the conditioning factors and Khatri (1994) generalizes the conditioning factor biases for a multiple output technology.

DATA

The national farm-level production material for the period 1947–91 is described in some detail in Thirtle *et al.* (1993). The three output aggregates are Crops (*Yc*), Horticulture (*Yh*) and Livestock and Livestock Products (*Ya*). The variable inputs are Divisia aggregated into four groups: (1) Hired labour (*Xl*), (2) Machinery running costs (fuel, machinery repairs and other) (*Xm*), (3) Intermediate inputs (fertilizer, other chemicals and packing) (*Xi*) and (4) Feed and dips (*Xa*). Vehicles and fixed capital in the form of building and other fixed improvements (*CAP*) are assumed to be quasi-fixed, as are the stocks of animals (*LS*). The total area of land in the commercial sector (*LAND*) is included as a fixed input.

The other conditioning factors, which are treated as fixed inputs, are research expenditures (*RES*), extension expenditures (*EXT*), a rainfall index (*RAIN*), world patents (*PAT*)[1] and a farmer education index (*ED*).[2] The construction of knowledge stock variables for these items is outlined in the appendix, along with the returns to R&D calculation. The expected prices are taken to be last year's actual prices (that is naive price expectations).

RESULTS

There are too many parameters in the profit function (3) to estimate the full model in one stage, so the residual profit function approach (Bouchet *et al.*, 1989; Khatri, Jayne and Thirtle, 1994) 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. As the supply and demand equations are estimated separately from the residual profit function, there are no estimated variance–covariances between the two sets of parameters. 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) at this stage. This allows 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 parameter estimates, most of which are significant at the 5 per cent confidence level (see Table 1). The R^2s of the estimated supply and demand system equations 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 normalizing), symmetry, monotonicity and the necessary conditions for global convexity are all satisfied by the estimated system. The estimated profit function is thus found to be acceptable with respect to its statistical performance and theoretical consistency.

Market distortions due to macro policy, credit policy and tax concessions imply that the usual opportunity cost measures for capital investments (such as market rental or interest on bank deposits) are not appropriate. We did not, therefore, attempt to derive the long-run solutions in the manner of Bouchet (*et al.* (1989) or Khatri (1994).

Estimated price and fixed factor elasticities

Economic theory predicts that all the own-price elasticities should be positive for outputs and negative for inputs. The fixed factor elasticities can be interpreted as the elasticities of outputs/inputs in response to a unit changes in the quasi-fixed, fixed or conditioning factors. The quasi-fixed inputs are stock variables that are endogenous in the long run, but changing their levels requires investment. Thus, in the short run, the costs of adjusting these stock levels may be considered in terms of forgone production. The levels of the conditioning variables are assumed to be beyond the control of farmers and the costs of adjusting these items are not directly incurred by farmers. Thus we may predict net negative output elasticities with respect to fixed and quasi-fixed factors and positive output elasticities with respect to the conditioning factors. The effects on individual outputs cannot easily be predicted, as changing capital stock levels or technology levels may favour certain outputs and also affect the variable input levels, which in turn affects output.

Table 1 presents the short-run price and fixed factor elasticities for the outputs and variable inputs, evaluated at the variable means. For inputs, a negative cross-price elasticity indicates complementarity and a positive result means that the variables are substitutes. For pairs of outputs, positive cross-price elasticities imply complementarity in supply and substitutes are indicated by negative cross-products. All the own-price elasticities for inputs and outputs have the expected sign, although the own-price elasticities for horticultural output and livestock are not significantly different from zero. With the exception of the numeraire, which is animal inputs,[3] the magnitudes of the own-price elasticities indicate inelastic price responses. These are the short-run elasticities and we might expect the long-run elasticities for outputs to be larger.

For outputs, significant complementarity appears to exist between horticulture and livestock production. The only significant input complementarity found is between labour and machinery running costs, which is not so odd in the short run: when output is expanding, existing machinery is more heavily utilized and more labour is required to do this. There appears to be significant substitutability between the intermediate inputs category (largely crop inputs) and labour and between the numeraire input (livestock inputs) and labour. This is possible since the use of pesticides, herbicides and dips and sprays has increased most rapidly (Thirtle *et al.*, 1993) and these may well be viewed as labour substitutes. There is also weaker evidence of complementarity between machinery running costs and intermediate inputs (perhaps between fertilizer use and mechanical weeding and harvesting) and substitutability between machinery running costs and the livestock inputs (the two enterprises are substitutes on many farms).

The lower half of Table 1 reports the elasticities for the fixed factors. The significant fixed factor elasticities for the outputs largely conform to the prediction above, in that the signs for livestock and land are negative. This would occur if the short-run cost of increasing herds or land area is forgone output. For capital, the sign is positive, suggesting that, even in the short run, capital and output move together. We return to this below, but the 'wrong' sign may

TABLE 1 *Elasticities for output supplies, input demands and fixed factors**

Price	Elasticity of						
	Yc	Yh	Ya	xl	Xm	Xi	Xa
Pc	**0.29**	**–0.01**	**–0.002**	**0.08**	**–0.03**	**0.14**	**1.52**
	1.71	–0.42	–0.05	1.63	–0.38	1.5	2.03
Ph	**–0.01**	**0.01**	**0.04**	**–0.02**	**–0.02**	**0.19**	**0.41**
	–0.42	0.15	2.23	–0.39	–0.29	2.3	3.30
Pa	**–0.002**	**0.11**	**0.05**	**–0.02**	**0.25**	**0.05**	**0.65**
	–0.05	2.23	0.86	–0.37	2.42	0.47	2.18
Wl	**0.02**	**–0.02**	**–0.01**	**–0.45**	**–0.15**	**0.22**	**0.35**
	1.63	–0.39	–0.37	–6.33	–2.11	2.76	2.72
Wm	**–0.01**	**–0.01**	**0.05**	**–0.10**	**–0.16**	**–0.10**	**0.24**
	–0.38	–0.29	2.42	–2.11	–1.81	–1.24	1.50
Wi	**0.04**	**0.16**	**0.02**	**0.25**	**–0.16**	**–0.47**	**–0.05**
	1.5	2.3	0.47	2.76	–1.24	–2.20	–0.14
Wa	**–0.34**	**–0.24**	**–0.15**	**0.27**	**0.27**	**–0.04**	**–3.12**
	–2.03	–3.30	–2.18	2.72	1.5	–0.04	–4.05
CAP	**0.70**	**0.76**	**0.37**	**0.32**	**0.54**	**0.72**	**11.96**
	5.35	15.23	9.41	4.44	6.09	6.64	3.61
LS	**–0.26**	**–0.18**	**–0.02**	**0.10**	**0.19**	**0.06**	**0.66**
	–0.89	–2.75	–0.21	0.98	1.24	0.37	0.30
LAND	**–1.28**	**–0.54**	**–0.04**	**–0.62**	**1.63**	**–0.85**	**–71.48**
	–1.02	–1.74	–0.11	–1.41	2.34	–1.13	–3.88
RES	**0.51**	**0.22**	**0.15**	**0.10**	**0.35**	**0.37**	**0.39**
	4.15	6.67	4.08	2.17	4.60	4.75	0.33
PAT	**0.19**	**0.07**	**–0.01**	**–0.05**	**–0.11**	**0.10**	**–0.67**
	1.97	2.99	–0.18	–1.44	–2.10	1.66	–1.03
EXT	**–0.02**	**0.08**	**0.04**	**–0.04**	**–0.04**	**–0.07**	**–15.05**
	–0.47	7.71	2.95	–2.44	–1.72	–2.85	–4.51
ED	**0.19**	**1.08**	**0.79**	**0.38**	**1.07**	**1.12**	**34.85**
	0.47	10.08	6.54	2.33	4.63	4.74	4.13

Note: *Price and fixed factor elasticities are in bold, below which are the corresponding *t*-ratios.

well result from capital itself having the wrong sign: it has a negative shadow price. All the *significant* elasticities of outputs with respect to conditioning factors are of the expected sign (positive) with significant elasticities throughout for the research knowledge stock. Thus R&D, extension, farmer education and private-sector activity all appear to increase the three outputs.

As with the outputs, all input elasticities are evaluated at the variable means and represent the short-run production responses. It appears to be true that more capital and more livestock means more use of all the variable inputs, which is reasonable. However, more land results in more machinery inputs, but less of the intermediate inputs. Similarly, R&D and education appear to be intermediate input using (leading to intensification, perhaps), but extension and private-sector spill-ins reduce input use. These results are plausible, but we do not pursue them here, since the elasticities of the fixed items have not been much considered in the literature.

Shadow prices

Table 2 reports the shadow prices of the quasi-fixed, fixed and conditioning factors, at the variable means. For long-run equilibrium, the shadow prices of the quasi-fixed factors should equal the rental value (market price per unit, per period) of the factor. Excess capacity/underutilization is indicated by an estimated shadow price less than the opportunity cost, meaning that there is an incentive to disinvest. Similarly, underinvestment is indicated by a shadow value greater than the opportunity cost (Berndt and Fuss, 1986; Morrison, 1986). However, government policy and uncertainty may cause sustained deviations from the optimal levels for capital goods. The negative real interest rates experienced by South Africa in the 1970s and 1980s and the index nature of the capital series complicate the interpretation of the results. The negative real interest rates together with positive real rental rates for capital are contradictory indicators of the opportunity cost of capital investment. Further, the index nature of the capital stock and livestock series means the derived shadow prices are indices (that is, they cannot be directly equated with the opportunity cost measures). Even so, we might predict that the shadow prices for capital items (without policy distortions) should be correlated with the expected real interest rates.

TABLE 2 *Estimated show values of the fixed and conditioning variables*

Factor	Shadow price	*t*-ratio[1]	*t*-ratio[2]
Capital	–2257.12	–2.37	–16.29
Livestock	–724.21	–1.16	–2.55
Land	273.68	3.54	14.92
Research	4.04	1.61	4.42
World patents	0.23	2.52	4.82
Extension	0.002	4.64	94.57
Education	–1378.5	–3.79	–22.53

Notes: [1]*t*-ratios derived using standard errors from the residual profit function parameters, holding parameters from supply and demand equations constant.
[2]*t*-ratios derived using standard errors from estimated supply and demand system, treating residual profit function parameters as constants.

However, interest rates are not the only determinants of the prices of capital items. The distortionary effects of policies are serious in the South African case, as Thirtle *et al.* (1993) noted. In the 1960s and 1970s, the overvalued exchange rate, subsidized farm credit and accelerated tax write-offs for capital purchases all combined with low and even negative real interest rates to make capital items artificially cheap. These policies appear to have led to considerable overcapitalization, for much of the period, at least until the early 1980s. Thus the mean shadow values of both physical capital (which is an aggregate of machinery, buildings and land improvements) and livestock capital are negative, as Table 2 shows.

The majority of parameters required for evaluating shadow prices are taken from the estimated supply and demand system and hence the second set of *t*-ratios are more appropriate. The negative and significant shadow value of the capital aggregate is consistent with the hypothesis of policy-induced overcapitalization. The shadow value of livestock capital is also negative, but if the shadow values are considered year by year (not reported here), the two series behave differently. This is shown in Figure 1, which plots indices of the shadow prices of livestock and capital against the real rate of interest.

The livestock price effect becomes negative in the mid-1950s, suggesting that the herds carried have tended to be too large for most of the period.

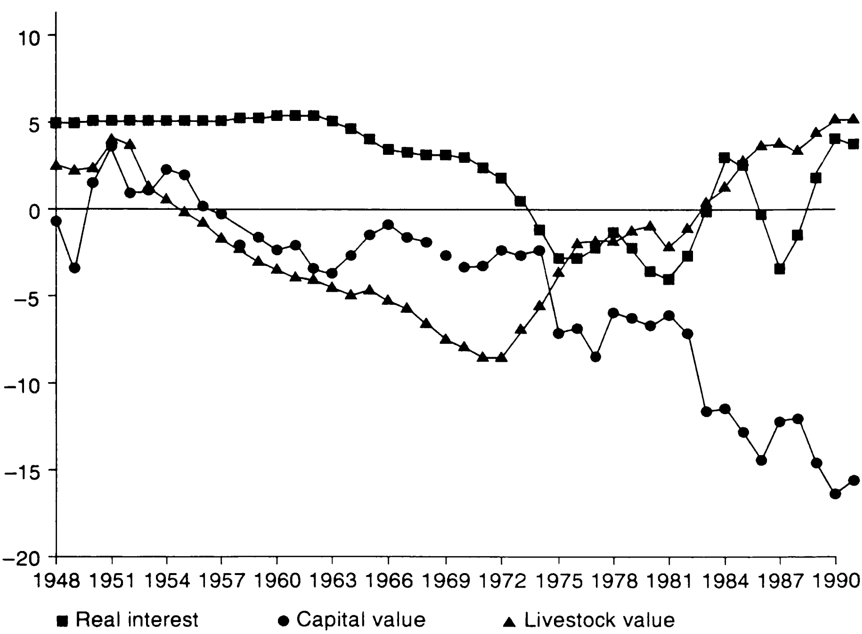

FIGURE 1 *Interest and values of capital and livestock*

However, by the end of the 1970s, sanctions began to affect the economy severely and the policies that had been designed to carry the farm vote came to an end. The gold price collapsed, the Rand was devalued and the credit subsidies and tax concessions were all but withdrawn, as financial stringency led to the end of negative real interest rates. Figure 1 shows that the real rate of interest became positive in 1983, which is the same year that livestock's shadow price turned positive. The correlation between interest rate movements and the livestock shadow price is not very good, but it is more than a coincidence that the arrival of hard times (that is, an end to distortionary policies) was accompanied by a return to positive shadow values, caused to an extent by reductions in herds forced by farm business failures.

Figure 1 shows that the index for the shadow value of physical capital behaves differently. It turns negative later, in 1957, but continues to become increasingly negative throughout the 1980s, instead of turning to give positive values. Indeed, Figure 1 suggests that there is a negative correlation between the real rate of interest and the shadow value of capital. However, the real difference is that capital adjusts slowly. Whereas herds can be reduced by slaughter, capital only adjusts at the rate of depreciation and follows the interest rate with a considerable lag.

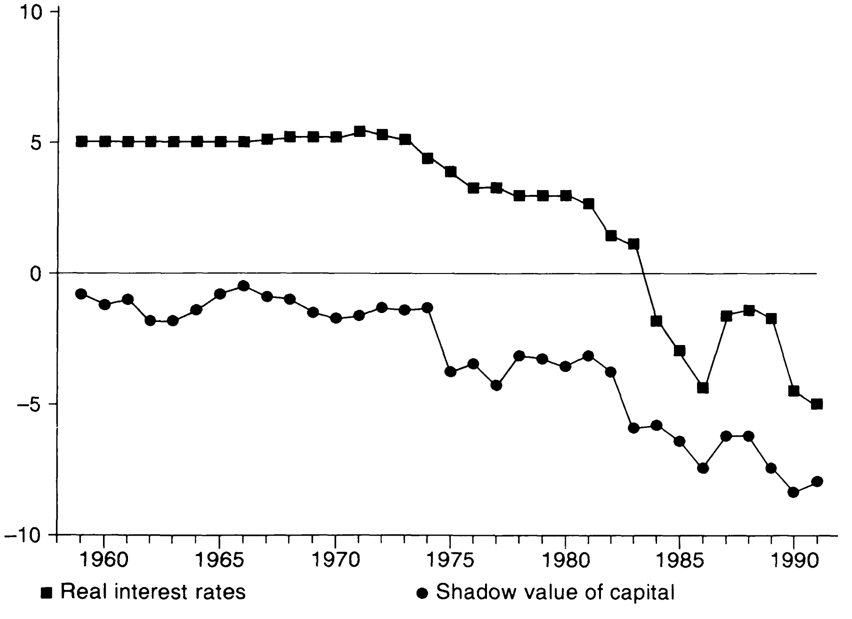

FIGURE 2 *Real interest and capital value, 11-year lag*

This is clear in Figure 2, which plots the capital price index against the real rate of interest lagged 11 years. Cointegration techniques were used to verify this lagged relationship. Both series are integrated of order one, meaning that they are stationary in first differences, and have no deterministic trends. Thus they may be cointegrated, which would suggest that the relationship is not spurious. This appears to be the case, since the Dickey–Fuller test statistic for the cointegrating regression is –4.3394, which is greater than the critical value of –3.5329. Real interest rates, lagged 11 years, explain over 90 per cent of the variance in the shadow value of the capital stock. These results show that the adverse effects of policy distortions are persistent; the shadow value of capital cannot be expected to be positive until the mid-1990s. We would argue that the investigation of the effects of macroeconomic variables on agriculture (see In and Mount, 1993) in developed countries should be extended to South Africa and Zimbabwe, where the macro distortions have been far more severe.

The shadow values of the remaining fixed factor, land, is more easily explained; it was negative up to 1965, after which it became positive and increasing in value, indicating an increasing marginal value product of land. This conforms with expectations as to the point at which land became a relatively scarce factor. The shadow price of land (evaluated at the variable means) is 274 rand per hectare. The time paths of the shadow value of land and the

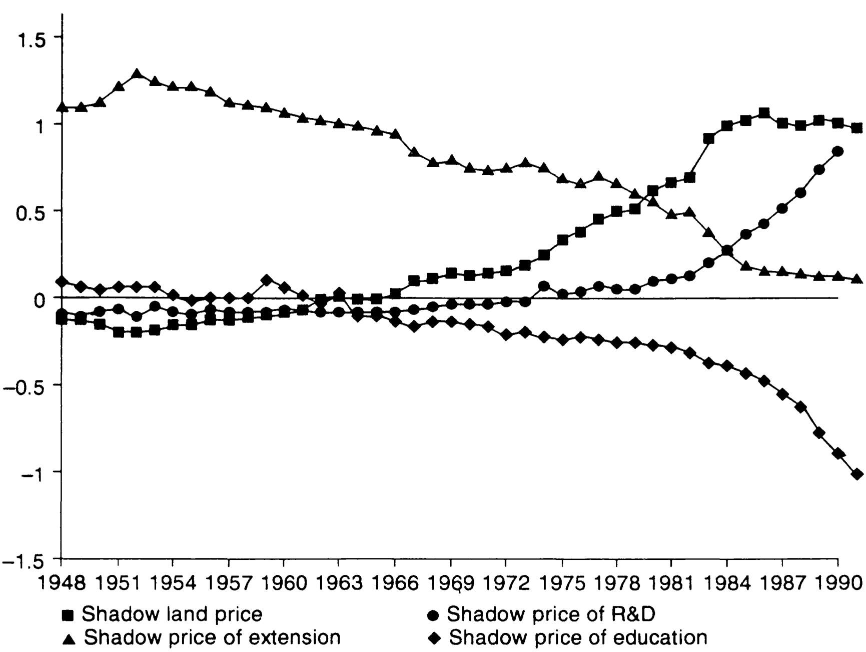

FIGURE 3 *Values of land, R&D, extension and education*

conditioning factors are shown in Figure 3. The land value index levelled out in the 1980s, as policies became less supportive of agriculture.

The conditioning factors complete Table 2. The shadow price for research of 4.04 is used to derive a (social) marginal internal rate of return (MIRR) to research of 44.25 per cent (the Appendix has further details). This is certainly a respectable rate of return on public expenditure. There are, however, the usual arguments that this figure may be somewhat diminished if we adjust for the deadweight losses associated with tax collection (the means of financing public expenditure) and the possibility that public funding may be crowding out private-sector research. Figure 3 shows that the shadow price of research was negative until 1974 and since then the value has risen at an increasing rate, suggesting that the research system is now making a considerable contribution to profitability (van Zyl *et al.*, 1993).

The shadow price of the international knowledge stock (representing spillovers) indicates that spillovers significantly affect productivity and profitability. This series is not included in Figure 3, as the values change very little over time. The shadow price of extension is surprisingly small (although highly significant), implying a near zero return on extension expenditure. Figure 3 shows that the shadow price of extension has been falling over the period, which suggests that South African commercial farmers have become less dependent on extension advice.

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[4] that education augments output but also augments input use (more than proportionately in the case of non-labour inputs). As the model relates to variable or short-run profit maximization, it is entirely possible that the productivity and profitability augmentation of the managerial input, which is perverse in the short run,[5] becomes positive in the long-run. Figure 3 shows that the shadow value of education was positive until the early 1960s, but has become increasingly negative since then.

Factor-saving biases of technological change

The output and input saving or using biases induced by research and the research-related variables are defined as the elasticities of the revenue or cost shares with respect to these conditioning factors, as shown in Table 3. A positive output/input bias (B_{ij}) implies that the revenue or cost share i is increasing with respect to conditioning factor j. Hence the technology variables (research stock and internationally available technology) are crop output augmenting. The input and output biases are reassuringly consistent. Research augments crop output, while using crop inputs (machinery and intermediate inputs) and saving livestock-related inputs. Similarly, international spillovers are crop output augmenting, crop-related intermediate inputs using and live-

TABLE 3 *Output and input biases of the conditioning factors**

	Output/input bias with respect to			
B (i,j)	Public research	Intermediate patents	Extension	Farmer Education
Crops	**0.28**	**0.13**	**0.04**	**–2.4**
Hort	–0.01	–0.001	**0.07**	**0.65**
Livestock	–0.09	–0.07	0.02	**0.36**
Labour	**–0.12**	**0.07**	**2.41**	**–5.73**
Machinery	**0.13**	–0.001	**2.41**	**–5.04**
Intermediate	**0.15**	**0.21**	**2.37**	**–4.9**
Feed & dips	**–0.19**	**–0.43**	**–10.06**	**22.02**

Note: *Figures in bold represent estimated biases that are significant at the 95 per cent level. Significance bounds for the input biases are evaluated treating the parameters derived from the residual profit function as constants.

stock input saving. Extension augments horticultural output and uses all inputs apart from livestock inputs for which it is saving. Finally, farmer education is horticulture and livestock augmenting, livestock input using, and saves all other inputs.

In terms of the induced innovation hypothesis, the results are those that might be expected for a developed country. Public-sector R&D is labour saving and machinery using; it is intermediate input using and animal input saving. This is somewhat unfortunate in a country with so few employment opportunities for the mass of the population, and South Africa would have benefited if the research system had been more able to fit its output of technology to local factor scarcities, rather than following the path of the developed Western countries.

CONCLUSIONS

The model provides a plethora of results, a summary of which has been presented above. Price and fixed factor elasticities are reported, indicating largely inelastic short-run responses to prices. The estimate of the return to public-sector research is 44 per cent and international technology spillovers are found to be a significant source of productivity growth. The negative shadow price of capital indicates serious resource missallocations (overcapitalization), probably resulting from market-distorting macro policies. Whatever the cause, overcapitalization has been socially costly, in terms of unemployment of farm workers, and has had high costs to farmers, in terms of reduced profits. The factor-saving biases of technological change appear to have exacerbated the factor price distortions, being labour saving and machinery using.

NOTES

[1]The patent data come from the US patent data base 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.

[2]This is years of secondary education of farmers and was kindly provided by the Commercial Farmers' Union. This set of conditioning factors can be shown to Granger cause changes in TFP (Khatri, Thirtle and van Zyl, 1994).

[3]The own-price elasticity of the numeraire input is derived residually as a linear combination of a large number of the estimated parameters and is unlikely to be accurate.

[4]Recall that all input and output elasticities with respect to education are positive and all but one of these elasticities are highly significant.

[5]We stop short of arguing that the current cost of undertaking investment in human capital is forgone output. Although this appeals to economic intuition, we know too little of the management structure.

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APPENDIX

*Compilation of the national research knowledge stock**

Denote the technological outflow in period t of real R&D expenditure F_t. Thus $F_t = \sum_j w_j E_{t-j}$, where w is a lag weight. The average lag is assumed to be six years; thus a simplifying approximation is to replace F_t with E_{t-6}, so we may write:

$$KS_t = E_{t-6} + (1-d)\,KS_{t-1} \tag{6}$$

and given that

$$KS_t = (1+g)\,KS_{t-1}, \tag{7}$$

where g is the growth rate of knowledge stock, we can write:

$$E_{t-6} = (d+g)\,KS_{t-1} \tag{8}$$

and so:

$$KS_t = \frac{E_{t-5}}{(d+g)} \tag{9}$$

Thus, given the growth rate of KS, we can derive a simple stock of knowledge. We assume that the rate of growth of KS is equal to the rate of growth of research expenditure when stock levels are low, thus a growth rate of 10 per cent was used. The agricultural research KS is represented by RES.

Compilation of the international knowledge stock

The growth rate of IKS is estimated to be around 10 per cent, depreciation is assumed to be 8.3 per cent (that is, 1/12) per annum and the average lag or gestation period for patents is assumed to be six years. We construct an international knowledge stock (PAT) in a similar manner to RES above.

*This knowledge stock construction follows that of Ito (1991).

Calculating the rate of return to research

The rate of return is calculated using the formula (Ito, 1991, p. 7):

$$\exp(r, L) = \int_0^\infty \left(\frac{\partial F}{\partial (RKS)} \right) \exp(-rt)\, dt \tag{10}$$

where L is the diffusion lag which implies, given a five-year diffusion lag, that:

$$re^{5r} = VMP_{RKS} \tag{11}$$

and, for example, a shadow price of RKS of 2.18 implies $r = 0.36$, or an internal rate of return of 36 per cent.