POLICY INDUCED INNOVATION IN SOUTH AFRICAN AGRICULTURE

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This paper examines whether the development path of South African agriculture has been consistent with its resource endowments. Within an induced innovation framework the two stage constant elasticity of substitution (CES) production function is used and results in a direct test of the inducement hypothesis which are applied to data for South African commercial agriculture for the period 1947-91. Cointegration is established, and an error correction model (ECM) constructed. The results indicate that factor price ratios are not the sole cause of factor-saving biases of technological change. Public choice and macroeconomic incentives played a significant role resulting in a distorted development path.

1. INTRODUCTION

The notion that at least some inventions may be induced by economic forces has been entertained by historians and economists at least since the 1920s (Mantoux, 1928, Hicks, 1932). There are by now several formulations of the relationship and well over one hundred empirical tests (Thirtle and Ruttan, 1987), the great majority of which corroborate some form of the inducement hypothesis. In many cases, the hypothesis is not clearly stated and the tests amount to no more than establishing a correlation between a measure of factor scarcity and an indicator of the direction, or factor-saving biases, of technical change. It is reasonable to infer that the inducement hypothesis implies that there should be a long run relationship between the direction of technical change and a measure of factor scarcities, such as relative prices. This paper examines the long run relationships using cointegration techniques and formalises the relationship by fitting an error correction model which separates the short run effects from the long run equilibrium path. A set of variables are included which, beyond price, are also important determinants of the bias in innovation, particularly the contrasted interest of large versus small farmers and the role of public goods.

2. MODELLING INDUCED INNOVATION

Hicks (1932) introduced the elasticity of substitution and the idea of "induced inventions", which endogenised the factor-saving bias of technical change at the level of the firm. However, the two concepts were not clearly separated, as Hicks noted in his Nobel lecture of 1973 (Hicks, 1977:2). This oversight led to critiques of induced innovation such as Blaug (1963) and Salter (1960), which were later shown to depend largely on the definition of the isoquant (Hayami & Ruttan, 1985:.86). The induced innovation hypothesis was rehabilitated when Ahmad (1966) introduced the innovation possibility curve (IPC), which is the envelope curve of all the isoquants (representing different technologies) that may be developed, given the state of scientific knowledge.

The IPC (together with its counterpart, the metaproduction function) form the basis of Hayami and Ruttan's (1985) application of the hypothesis to aggregate agricultural output in a long-run historical development context. They argue that rapid growth in agricultural productivity is generated by technical change that facilitates the substitution of relatively abundant (hence cheap) factors for relatively scarce (hence expensive) factors in the economy (p.73). Their model is developed by exploiting the identity

$$Q/L = (Q/A)(A/L) \qquad (1)$$

where Q is output, L is labour, and A is land. Land area per worker (A/L) is increased by mechanical technical change, which allows power to be substituted for labour. Similarly, biological advances, such as high-yielding, fertilizer-responsive seed varieties, raise the average product of land (Q/A) and may be referred to as biological/chemical technical change. Thus, technical changes are represented as movements around the IPC and changes in factor ratios are induced, to a significant extent, *by the long-term trends in relative factor prices* (Hayami and Ruttan, 1985, p.181).

The agricultural histories of the United States, where labour was the relatively scarce factor, and Japan, where land was scarce, show that Japanese agricultural technology was relatively yield-increasing (land-saving relative to labour), whereas technical change in the USA was labour-saving relative to land. Biological and chemical technology dominated in Japan, while mechanical technical change was relatively more important in the USA.

3. THE SOUTH AFRICAN EXPERIENCE

This framework is used to analyse the relative factor saving bias for South African agriculture. A comparison will be made between the development path that is expected, given South Africas' resource endowments, and the actual path taken. The data used in the analysis are for the commercial agricultural sector of the Republic of South Africa, for the period 1947-91. The main source is the *Abstract of Agricultural Statistics* Republic of South Africa, (1993) supplemented by historical material and unpublished information from the Department of Agriculture. These data were used for total factor productivity measurement (Thirtle et al.,1993) and estimation of a dual profit function (Khatri et al., 1994). The land measure is the total hectarage of agricultural land and the land price is the rental value. Labour is all hired labour and the price is the wage for hired labour. Fertilizer is a constant price series for an aggregate of all fertilizer and the price is for the average fertilizer mix. The machinery series is the service flow (interest, depreciation and running costs) from the capital stock of machinery, implements, motor vehicles and tractors, taken from Thirtle et al. (1993). This avoids the problem of mixing stock and flow variables.

Figure 1 shows that after 1950 there is a remarkably close relationship between the ratio of machinery to labour and the price of labour relative to the price of machinery. In the

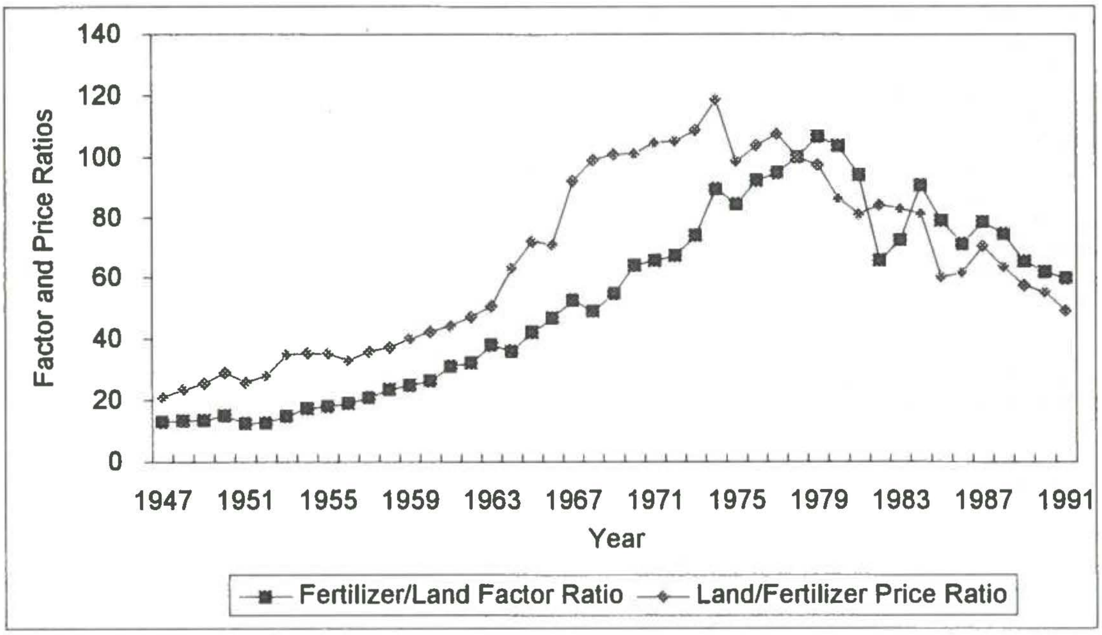

Figure 1: **Correlation of the Machinery/Labour Factor Ratio and the Labour/Machinery Price Ratio**

first few years after the end of the war, the arable area was being extended, which led to increased use of labour (especially since harvesting was not mechanised) as well as machinery. Also, supplies of agricultural machinery and equipment were limited and animal power was still important. Then, for three decades the price of machinery falls relative to the price of labour and the machinery labour ratio rises, as the induced innovation hypothesis predicts. Then, after 1981 the favourable credit and tax policies had largely gone, the gold price had plummeted and the rand had been drastically devalued (Thirtle et al 1993). These events had a combined effect of making a domestic input like labour far cheaper relative to capital and led to a dramatic reversal of the historical trend, with labour use increasing as it was substituted for expensive capital. The induced innovation hypothesis appears to be well supported by these data. The lack of lags between price changes and quantity adjustments is partly caused by the fact that the machinery series is the service flow rather than the capital stock. However, the claim that the process is induced innovation rather than factor substitution must rest on Hayami and Ruttan's (1985) argument that long-run factor substitution is only made possible by innovation.

Figure 2 shows that the fertilizer/land factor ratios and price ratios are also highly correlated. There was some growth in

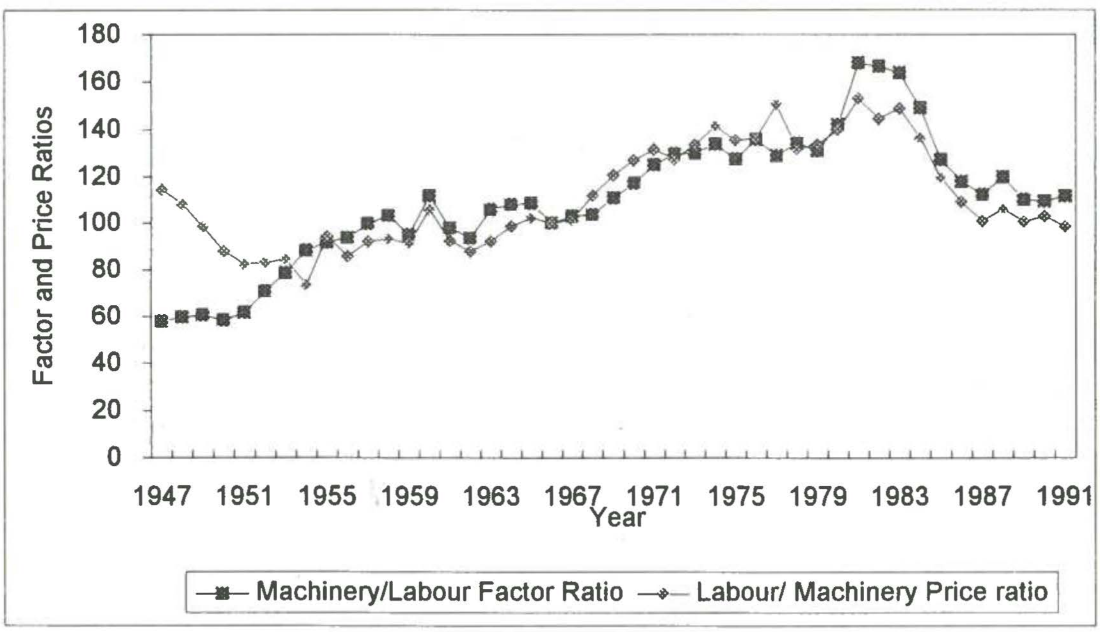

Figure 2: **Correlation of the Fertilizer/Land Factor Ratio and the Land/Fertilizer Price Ratio**

land during the period 1947 to 1959, when the cultivated area was being expanded. The fertilizer/land factor ratio shows two distinct trends, growing rapidly at 7.38% per annum from 1947-79 and then falling at a rate of -3.98% per year. The decrease in fertilizer use in 1975 can be attributed to the rise in the relative price of fertilizer that resulted from the OPEC oil crisis. Then, the fertilizer/land ratio rose again as land rents increased rapidly in the late 1970s. Groenewald (1986) and van Schalkwyk and Groenewald (1992) suggest that many farmers in South Africa, particularly grain farmers, over-fertilized, so the reduction contributed to the increase in productivity growth reported by Thirtle et al. (1993).

3. A DIRECT TEST OF THE INDUCED INNOVATION HYPOTHESIS

The model of de Janvry et al (1989), which exploits the tractability of the two-stage constant elasticity of substitution production function, incorporating transaction costs and collective action as determinants of the factor saving biases of technological change, is used in this analysis. As the transaction costs of labour (supervising, negotiating, information costs) increase with farm size there will be an increasing bias in research towards labour saving technology if large farmers' demands prevail. Conversely, the transaction costs for land decrease with farm size because the fixed cost in land implies that the price of land declines with farm size. This effect decreases the bias towards land saving technology if small farmer demands prevail. Frisvold (1991) uses this framework to test induced innovation in the US. Cointegration was used to establish long run relationships and an error correction model was estimated. This separates the short run effects (factor substitution) from the long run equilibrium path.

4. RESULTS

Table 1 shows the error correction model results which were derived using the general to specific approach of Hendry and Richard (1982). The data series for R&D, extension and patents are from Thirtle & Van Zyl (1994). The patents are counts of chemical and mechanical patents, pertaining to agriculture, registered by all countries in the US. They are used both to account for private R&D activity and to try to capture some of the international R&D spillovers. The model was customised to suit the special problems of South Africa by including dummy variables to capture the effects of taxation policy, interest rates and the control of labour by means of the Pass Laws. The dummy variable for tax policy covers the period up to 1982, when concessions such as agricultural buildings subsidies and rapid tax write-offs for machinery were withdrawn. The dummy for the negative real interest rate covers 1973-1982 an 1985-1987 the Pass Law dummy covers 1968-1985. Farm size is used in the model to represent transaction costs of land purchases and sales of labour management, as in de Janvry *et al.* (1989). All the variables were integrated of order one except mechanical patents. Cointegration and hence long run relationships were established between the mechanical/labour factor ratio and the fertilizer/land factor ratio and the corresponding variables in table 1.

In the machinery/labour equation, the short run own price coefficient may be interpreted as the direct elasticity of substitution. The value of -0.37 suggests that short run substitution possibilities are limited. The land/labour price ratio was not significant in the short run and neither were any of the other first differences of the variables. The dummies for tax concessions and negative interest rates, which are I(0) and are hence included in the levels, are significant and positive. The Pass Law dummy variabe was not significant.

The long run results, derived from the adjustment terms, are consistent with the induced innovation hypothesis. The negative coefficient on the long-run own price variable, having an elasticity of -0.47 (-0.33/0.70), indicates that a decrease in the machinery/labour price ratio generates labour-saving technological changey The error correction term for the machinery/labour equation is -0.70 which indicates that when the system is not in equilibrium, there is

Table 1: Unrestricted ECM Results: Significant Variables Only

Variable	Machinery/Labour Ratio	Fertilizer/Land Ratio
SHORT RUN		
CONSTANT	3.21 (3.5)	-5.11 (-4.5)
D(Price of machinery/Price of labour)$_t$	-0.37 (-3.4)	
D(Price of fertilizer/Price of land)$_t$		-0.39 (-2.7)
D(Price of land/Price of labour)$_t$		0.17 (1.9)
Taxation policy variable	0.16 (2.6)	
Real interest rate variable	0.09 (2.5)	
Rainfall		0.12 (1.2)
LONG RUN		
(Machinery/Labour)$_{t-1}$	-0.70 (-5.6)	
(Fertilizer/Land)$_{t-1}$		-0.40 (-4.7)
(Price of machinery/Price of labour)$_{t-1}$	-0.33 (-2.0)	
(Price of fertilizer/Price of land)$_{t-1}$		-0.36 (-3.3)
(Price of land/Price of labour)$_{t-1}$	0.12 (2.8)	0.14 (1.9)
R&D expenditure $_{t-1}$	0.09 (1.4)	
Chemical patents$_{t-1}$		0.06 (1.6)
Extension expenditure$_{t-1}$		0.20 (1.7)
Farm size$_{t-1}$	0.23 (1.5)	
R^2	0.66	0.51
DW	2.3	1.9

The critical t values are 1.3 for 90 percent confidence, 1.68 for 95 percent and 2.02 for 97.5%

70 percent correction towards the long run equilibrium level in the current period. The positive sign on the land/labour price coefficient is in agreement with Frisvold's (1991) prediction. Public R&D expenditure is positive and significant with a long-run elasticity of 0.13, (0.09/0.70). The long run elasticity of 0.33, (0.23/0.70), for farm size agrees with de Janvry et al.'s (1989) argument that larger farms will have a greater machinery-using bias, due to the costs of labour management.

The fertilizer/land model, did not perform as well in terms of explaining the deviations in the dependent variable with an adjusted R^2 of 0.51. The short run coefficient on the fertilizer to land price ratio, of -0.39, is the direct partial elasticity of substitution suggests that the short run substitution possibilities between land and fertilizer are very limited. The land/labour price ratio coefficient is positive and significant in the short run The reliance of fertilizer application on the weather is reflected by the rainfall variable.

The error correction term for the fertilizer to land equation is -0.40. This indicates slow adjustment towards the long run equilibrium level in the current period. The negative sign shows that the direction of correction is towards equilibrium. The long-run own price elasticity of -0.90, (-0.36/0.40) indicates that a decrease in the fertilizer/land price ratio generates land-saving technological change, in the manner predicted by the induced innovation hypothesis. The negative sign on the land/labour price coefficient is in agreement with Frisvold's (1991) prediction. The patent variable, representing international technological spillovers is positive and significant and so is the effect of extension efforts having long run elasticities of 0.15, (0.06/0.40), and 0.50, (0.20/0.40), respectively. The public R&D expenditures fail to show any effect due to collinearity with these two variables, but this weakness does suggest that the South African research system has tended to adapt foreign technology rather than developing its own basic genetic material.

5. CONCLUSION

This paper tests Hayami and Ruttan's (1985) induced innovation hypothesis for South African agriculture. The two stage CES production function leads to estimating equations that directly test the inducement hypothesis, by making factor ratios functions of factor price ratios. The model also incorporates the variables that generate the new technologies (public R&D and extension and private patents) and variables that affect the factor saving biases, such as farm size, negative real interest rates and tax concessions.

Cointegration is established and an error correct model constructed, which separates short run effects, such as factor substitution, from the long run equilibrium, which incorporates induced technological change. All of these tests corroborate the inducement hypothesis and the empirical results indicate that average farm size, research and extension expenditures, favourable tax and interest rate policies are also important determinants of the observed rates and biases of technological change. This suggests there is more than prices to the bias of technical change, public choice variables, public good delivery and macroeconomic policies also matter. Hence the results support the need to look not only at price (the Hayami and Ruttan formulation) but also at the structural, political and macro context to understand the bias of technical change.

In the new South Africa, more attention should be focused on the technological needs of small scale farmers, as the combination of the lobbying power of the large scale commercial farmers and the policies followed by the apartheid regime have influenced the allocation of R&D expenditures between labour and land-saving technical change. This has distorted the technological bias towards labour-saving technical change, which is hardly appropriate for a labour-surplus economy, in which the small farmers in the ex-homelands face chronic land scarcity.

REFERENCES

AHMAD, S. (1966). On the Theory of Induced Innovation. Economic Journal, Vol 76:344-357.

BLAUG, M. (1963). A Survey of the Theory of Process-Innovation. Economica, Vol 63:13-32. Reprinted in Chapter 4 of The Economics of Technological Change, ed. by N. Rosenberg. Harmondsworth, England: Penguin, 1971.

DE JANVRY, A., SADOULET, E. & FAFCHAMPS, M. (1989). Agrarian Structure, Technological Innovations, and the State in The Economic Theory of Agrarian Institutions, ed. by P.Bardhan

DIRECTORATE OF AGRICULTURAL ECONOMIC TRENDS. (1993). Abstract of agricultural statistics. Pretoria: Department of Agricultural Economics and Marketing.

FRISVOLD, G.B. (1991). Endogenous Technological Change in U.S. Agriculture. A direct test of the induced innovation hypothesis. USDA, Technical bulletin No.1790

GROENEWALD, J.A. (1986). The Performance of Past Food, Agricultural and Trade Policies; Implications for the Future. Agrekon, Vol 25(2):53-81.

HAYAMI, Y. & RUTTAN, V. (1985). Agricultural Development: An International Perspective. Rev.Ed. Baltimore: Johns Hopkins University Press.

HENDRY, D.F. & RICHARD, J.F. (1982). On the formulation of empirical models in dynamic econometrics. Journal of Econometrics, Vol 20:3-33.

HICKS, J. (1932). The Theory of Wages, 1st ed. London: Macmillan and Co.

HICKS, J. (1977). Economic Perspectives: Further Essays in Money and Growth. Oxford: Clarendon Press.

KHATRI, Y., THIRTLE, C. & VAN ZYL, J. (1994). South African Agricultural Competitiveness: A Profit Function Approach to the Effects of Policies and Technology. Invited Paper for the International Association of Agricultural Economists conference, Harare, Zimbabwe, 1994. To be published in IAAE Proceedings, 1995.

MANTOUX, P. (1928). The Industrial Revolution in the Eighteenth Century, Revised Edition, Jonathan Cape, London.

SALTER, W.E.G. (1960). Productivity and Technical Change, 1st ed. Cambridge: Cambridge University Press.

THIRTLE, C. & RUTTAN, V. (1987). The Role of Demand and Supply in the Generation and Diffusion of Technical Change, Fundamentals of Pure and Applied

Economics, Vol.21, Harwood Academic Publishers, London.

THIRTLE, C., SARTORIUS VON BACH, H.J. & VAN ZYL, J. (1993). Total Factor Productivity in South African Agriculture, 1947-1991. Development Southern Africa, Vol 10:301-318.

THIRTLE, C. & VAN ZYL, J. (1994). Returns to Research and Extension in South African Commercial Agriculture, 1947-91. South African Journal of Agricultural Extension, Vol 23:21-27.

VAN SCHALKWYK, H.D. & GROENEWALD, J.A. (1992). Regional Analysis of South African Agricultural Resource Use and Productivity. Agrekon, Vol 31:76-82.