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Testing the Induced Innovation Hypothesis in South African Agriculture

(An Error Correction Approach)

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Apparently factor prices do matter in agricultural production and in the selection of production technology. And in South Africa, more attention should be focused on the technological needs of small-scale farmers. Current policies sustain the bias toward labor-saving technical change, hardly appropriate for a labor-surplus economy in which small farmers in the former homelands face a chronic scarcity of land.

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Summary findings

Thirtle, Townsend, and van Zyl investigate whether factor prices matter in agricultural production and in the selection of production technology.

Each stage of the analysis corroborates the inducement hypothesis, which implies that factor prices do matter in agricultural production and in the selection of production technology.

The empirical results also suggest that observed rates and biases of technological change are influenced by average farm size, by spending on research and extension, and by favorable tax and interest-rate policies.

In South Africa, the authors contend, more attention should be focused on the technological needs of small-scale farmers. The lobbying power of the large commercial farmers, combined with policies followed under apartheid, must have influenced the allocation of research and development funds between labor- and land-saving technical change. This will have distorted the technological bias toward labor-saving technical change, which is hardly appropriate for a labor-surplus economy in which small farmers in the former homelands face a chronic scarcity of land.

These results show that factor prices do matter in agricultural production and the selection of production technology. And there seems to be merit to the World Bank's usual policy prescription — structural adjustment and market liberalization — for economies in which prices are controlled and distorted.

They investigate the role of factor prices by applying cointegration techniques to a model of induced innovation based on the two-stage constant elasticity of substitution production function. This approach results in direct tests of the inducement hypothesis, which are applied to data for South African agriculture for the period 1947–92. They check the time series properties of the variables, establish cointegration, and construct an error correction model (ECM) that allows factor substitution to be separated from technological change. Finally, they subject the ECM formulation to tests of causality, which show that the factor price ratios induce the factor-saving biases of technological change.

This paper — a product of the Office of the Director, Agriculture and Natural Resources Department — is part of a larger effort in the department to design appropriate agricultural policies. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Melissa Williams, room S8-222, telephone 202-458-7297, fax 202-522-1142, Internet address mwilliams@worldbank.org. November 1995. (31 pages)

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TESTING THE INDUCED INNOVATION HYPOTHESIS IN SOUTH AFRICAN AGRICULTURE: AN ERROR CORRECTION APPROACH[1]

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A major component of recent World Bank advice in the field of agriculture usually involves structural adjustment and market liberalization. This advice is only relevant when it can be shown that factor prices do matter in agricultural production and the choice of production technology. While this issue has been investigated many times utilizing a variety of methodologies, results have often been less than conclusive. Thus, the induced innovation hypothesis is not necessarily always accepted.

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. In some cases, the results are poor; in nine tests intended to show that changes in the land/labor price ratio cause changes in the land/labor ratio, five outcomes are inconsistent with the hypothesis. This leads Ruttan et. al. (1978) to postulate "an innate labor saving bias" in the technological possibilities. Thus, the hypotheses tested are irrefutable, because they "fail to forbid any observable state of affairs" (Lakatos, 1970, p.100). It is obvious that this issue is important in the World Bank's work in agriculture, particularly as a major component of policy prescriptions often involve major structural adjustment and market liberalization initiatives.

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. The variables should not diverge too much in the long run, so although there may be short run deviations, there should be some equilibrating mechanism that brings them back together eventually (Granger, 1986). Thus, cointegration techniques allow formal testing of the inducement hypothesis. Specifically, the time series properties of the series can be established, to ensure that there can be a non-spurious relationship between the variables. This also allows different formulations of the hypothesis to be compared. Then, if a cointegrating vector exists, an error correction model can be constructed to determine the long run relationships and the direction of causality can also be established.

The next section critically examines variants of the hypothesis and discusses the difficulties involved in empirical tests. This is followed by a section which describes the two-stage constant elasticity of substitution (CES) model and explains why it is still popular, despite the availability of flexible functional forms that are less restrictive. The subsequent section describes the data and applies time series analysis to determine the properties of the variables and to establish cointegration. This leads to OLS regressions in the levels, which corroborate the induced innovation hypothesis. The next section formalizes the relationships by fitting an ECM, which separates the short run effects (factor substitution) from the long run equilibrium path, which depends on technological innovation. Finally, the ECM is tested to establish causality.

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, p2). 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 and Ruttan, 1985, p.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

$$Q/L \equiv (Q/A)/(A/L) \tag{1}$$

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. Hayami and Ruttan's three equation tests of the inducement hypothesis regressed the logarithms of the factor ratios (land/labour, fertilizer/land and machinery/labour) on the logarithms of the factor price ratios. If the coefficient of the relevant price ratio is negative and significantly different from zero, the result is considered to corroborate the inducement hypothesis.

However, the test is entirely ad hoc and the distinction between factor substitution and induced innovation is not clear. That the causality runs from price ratios to factor ratios is not tested and nor is the assumption that long-run factor substitution depends upon technical change. These simple tests are not derived from a particular functional form of the production relationship, but the revised edition of Hayami and Ruttan (1985) includes two-stage tests based on the two-stage constant elasticity of substitution (CES) production function. The two-stage CES is estimated, with time-dependent factor augmentation coefficients, to produce estimates of the Allen elasticities of factor substitution and the biases of technical change.

Then, in the second stage, the total changes in factor shares are split into factor substitution and technical change and the share-based bias measures are plotted against relative prices, to test the inducement hypothesis. Similar two-stage CES approaches are used by Kawagoe, Otsuka and Hayami (1986), who also apply the model to the USA and Japan, Thirtle (1985), who considers US wheat production, and Karagiannis and Furtan (1990) who use Canadian data. Binswanger (1974, 1978) pioneered a similar path, applying the translog cost function, and using relative factor prices to explain the residual factor shares, net of factor substitution. The "isotech" analysis of Nordhaus (1973), which has been extended by McCain (1977) and Wyatt (1986) is similar to the Hayami and Ruttan approach, but has not been taken on board by agricultural economists. These developments are more fully outlined by Thirtle and Ruttan (1987).

However, the "traditional model", developed by Binswanger and many others uses a time trend in estimating the biases of technical change. Clark and Youngblood (1992) argue that the time series properties of all the variables must be established prior to estimation, since the "parameter estimates for the traditional model are valid only if all independent variables are stationary and the dependent variables are driven by a deterministic time trend." They correctly suggest that estimates of the biases of technical change should be based on measures such as research expenditures or publications. This is common practice in the duality-based cost and profit function approaches to technical change in agriculture, which are conveniently summarised by Evenson and Pray (1991, pp.185-194). The "technology variables", such as R&D and extension expenditures, that shift the flexible functional form over time, are included in the specification of the "meta-profit" function.

The combination of duality and flexible functional forms employed in studies of this type increases the level of technical sophistication considerably, but is far more demanding in terms of data. The alternative approach, based on the two-stage CES function is parsimonious in this respect and the functional form itself gives rise to estimating equations that allow direct testing of the inducement hypothesis.

A DIRECT TEST OF THE INDUCED INNOVATION HYPOTHESIS

The model developed by de Janvry et al. (1989) exploits the tractability of the two-stage CES by incorporating transaction costs and collective action as determinants of the factor-saving biases of technological change. Frisvold (1991) uses the model straightforwardly to test the induced innovation hypothesis, and it is this approach that is followed here. The two-stage (CES) production function forms the starting-point

$$Q = [\gamma(Z_1)^{-\rho} + (1-\gamma)(Z_2)^{-\rho}]^{-1/\rho} \tag{2}$$

$$Z_1 = [\beta(L)^{-\rho_1} + (1-\beta)(E_m M)^{-\rho_1}]^{-1/\rho_1} \tag{3}$$

$$Z_2 = [\alpha(A)^{-\rho_2} + (1-\alpha)(E_f F)^{-\rho_2}]^{-1/\rho_2} \tag{4}$$

where Q is aggregate agricultural output, Z_l is the labouresue input group (comprising labour, L, and machinery, M), Z_2 is the landesque inputs (land, A, and fertilizer, F), E_m and E_f are efficiency parameters and all the Greek letters represent the usual substitution and factor share parameters of the CES function. Rearranging the first order conditions from the profit maximisation problem and assuming equilibrium, so that marginal products are equal to factor prices, gives the estimating equations
for (3) and (4)

$$Ln\left[\frac{M}{L}\right] = \sigma_1 Ln\left[\frac{1-\beta}{\beta}\right] + [\sigma_1 - 1] Ln E_m - \sigma_1 Ln\left[\frac{P_m}{P_l}\right] \tag{5}$$

$$Ln\left[\frac{F}{A}\right] = \sigma_2 Ln\left[\frac{1-\alpha}{\alpha}\right] + [\sigma_2 - 1] Ln E_f - \sigma_2 Ln\left[\frac{P_f}{P_a}\right] \tag{6}$$

where the P_is are the input prices and the direct partial elasticity of substitution of labour for machinery is σ_1 and that for fertilizer and land is σ_2 (Kawagoe, Otsuka and Hayami, 1986).

Thus, the two-stage CES approach leads to a direct test of the inducement hypothesis, since factor ratios are regressed on a constant, the price ratios and the efficiency parameters. If the current factor price ratios are significant in explaining factor substitution, the coefficients of these terms can be interpreted as direct partial elasticities of substitution. If lagged price ratios explain the factor ratios, then the inducement hypothesis is corroborated (Frisvold, 1991).

The treatment of the efficiency parameters remains somewhat arbitrary. De Janvry et al. (1989) and Frisvold (1991) assume that the efficiencies are functions of research activities, so

$$E_{f,m} = E_{f,m}[\theta, B, R, t] \tag{7}$$

where θ is a vector of shares of past public sector research budgets, B, allocated to land-saving technical change (E_f) and labour-saving technical change (E_m), R is a vector of past private sector research expenditures and t is a time trend representing exogenous change in scientific knowledge. The vector of share parameters, θ, allocating the research budget between activities, itself depends on expected relative factor prices and explicit behavioural assumptions regarding the government research budget allocation, so that

$$\theta^* = (P_m^e/P_l^e,\ P_f^e/P_a^e,\ P_a^e/P_l^e,\ B,\ R,\ t), \tag{8}$$

where the price ratios are all expectations. De Janvry et al. (1989) also include transaction costs to explain research allocations. As the transaction costs for labour (supervising, negotiating, information costs) increase with farm size there will be an increasing bias in research towards labour saving technology. Conversely, the transaction costs for land decrease with farm size because the fixed cost in land transactions implies that the price of land declines with farm size. This effect decreases the bias towards land saving technology. De Janvry et al (1989) substitute (7) and (8) into (5) and (6) so the determinants of the optimal technical changes and factor ratios appear in their reduced form equations.

The same approach is followed here, but the model is adapted to the South African case. The factor ratios are assumed to be functions of the past R&D expenditures, that generated the technologies, extension expenditures that transmitted the results to the farmers, so diffusing the technology, and the education level of the farmers, which affects both their own creative and managerial abilities, and their skill in appraising and adapting exogenous technologies. Patent data is used to account for private sector research and farm size is included as a cause of factor saving biases. The policy distortions of the apartheid period are also allowed for by including dummy variables for tax concessions, negative real interest rates for farm credit, and the operation of the Pass Laws.

TIME SERIES ANALYSIS OF THE DATA

The Data

The data are for the commercial agricultural sector of the Republic of South Africa, for the period 1947-92. 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. The series for R&D, extension, farmer education and patents are from Thirtle and 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 and 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 effect 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 subsidises and rapid tax writeoffs for machinery were withdrawn. The dummy for the negative real interest rate covers 1973-1982 and 1985-87 the Pass Law dummy covers 1968-1985. Farm size is used in the model to represent transaction costs of land purchases and sales and of labour management, as in de Janvry et al. (1989).

Order of Integration

Cointegration techniques are used to establish valid relationships between the variables. If the variables are cointegrated, then deviations from the long run equilibrium path should be bounded. In simple cases two conditions must be satisfied for variables to be cointegrated. First, the series for the individual variables should be integrated of the same order and second, a linear combination must exist that is integrated of an order one less than the original variables; that is, if the variables are integrated of order one (denoted I(1)), the error term from the cointegrating regression should be stationary (or I(0)).

The time series properties of the variables, all in logarithms, are reported in Table 1[1]. The standard Dickey-Fuller (Dickey and Fuller 1981) (DF) test and the Sargan and Bargava (1983) CRDW test are used to determine the order of integration. Column two shows that all the variables are first order autoregressive (AR) processes, which indicates that the error terms in the DF tests are white noise, as required. This was confirmed using the Ljung and Box (1978) Q^* statistic for serial correlation, which is appropriate for small samples.

The next column shows that the DF test statistics indicate that all the variables are non-stationary in the levels, except for mechanical patents (all except the -3.81 for mechanical patents are greater than the critical value of -2.90). However, the DF test values for the first differences are all less than the critical value, indicating that all the variables are I(1), except for mechanical patents, which appears to be I(0). The CRDW tests in column four confirm the I(1) results and suggest that mechanical patents is also borderline I(1). The Dickey-Fuller ϕ_3 test

[1] The Pass Laws dummy is excluded at this stage and so is farmer education, as these two variables were not significant in any of the regressions.

(Dickey and Fuller 1981) in the last column jointly tests for a unit root and a deterministic trend. The test statistics for all the variables except mechanical patents are less than the critical value, indicating that there are no deterministic trends.

Table 1: Testing the Variables for Order of Integration

Variable Name and Abbreviation	AR order	DF Tests	CRDW Tests	D-F ϕ_3 Tests
LOG RATIO MACHINERY/LABOUR (M/L)	1	-2.40	0.07	3.07
Δ LOG RATIO MACHINERY/LABOUR		-5.66	1.75	
LOG RATIO PRICE MACHINERY/LABOUR (P_M/P_L)	1	-1.36	0.18	1.37
Δ LOG RATIO PRICE LABOUR/MACHINERY		-7.48	2.29	
LOG RATIO FERTILIZER/LAND (F/A)	1	-1.79	0.03	2.24
Δ LOG RATIO FERTILIZER/LAND		-5.94	1.85	
LOG RATIO PRICE FERTILIZER/LAND (P_F/P_A)	1	-1.22	0.03	1.26
Δ LOG RATIO PRICE FERTILIZER/LAND		-5.93	1.85	
LOG RATIO PRICE LAND/LABOUR (P_A/P_L)	1	-1.41	0.12	2.48
Δ LOG RATIO PRICE LAND/LABOUR		-6.76	2.11	
LOG OF REAL R&D EXPENDITURES (RD)	1	-1.07	0.04	1.63
Δ LOG OF REAL R&D EXPENDITURES		-5.32	1.42	
LOG OF REAL EXTENSION EXPENDITURES (EXT)	1	-2.07	0.12	4.28
Δ LOG OF REAL EXTENSION EXPENDITURES		-7.57	1.97	
LOG OF FARM SIZE (SIZE)	1	-0.37	0.02	1.68
Δ LOG OF FARM SIZE		-5.15	1.65	
LOG OF CHEMICAL PATENTS (CHP)	1	-2.68	0.11	6.45
Δ LOG OF CHEMICAL PATENTS		-8.46	2.54	
LOG OF MECHANICAL PATENTS (MEP)	1	-3.81	0.66	13.50
Δ LOG OF MECHANICAL PATENTS		-6.26	1.95	
Critical values	**All variables**	**-2.90**	**0.67**	**6.73**

Apart from establishing that all but one of the variables have the same time series properties and may cointegrate, these results indicate that for South Africa, the induced innovation hypothesis should be formulated in the original manner (Hayami and Ruttan, 1985), with factor ratios being a function of factor price ratios. This is contrary to Tiffin and Dawson (1995) who suggest modifying the hypothesis to make *changes* in factor ratios a function of factor price ratios. This result comes from finding that for Hayami and Ruttan's (1985) US data, the factor ratios are I(1), while the price ratios are I(2).

Cointegrating OLS Regressions

Having established that the variables are integrated of the same order, the next stage is to test for cointegrating vectors which imply that non-spurious long-run relationships exist and super-consistent (Stock, 1987) OLS results. We begin by considering the key relationship between factor ratios and factor prices, before incorporating the range of other 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 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. Indeed regressing the factor ratio on the price ratio from 1954 onwards gives an R^2 of 0.94. 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[2].

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.

[2] The main reasons for using South African data to test the inducement hypothesis is that the quality is as good as any for the western countries and there are price reversals of this magnitude, so that we avoid just fitting trends and can look at turning points.

Figure 1: Correlation of Machinery/Labour Factor and Price Ratios

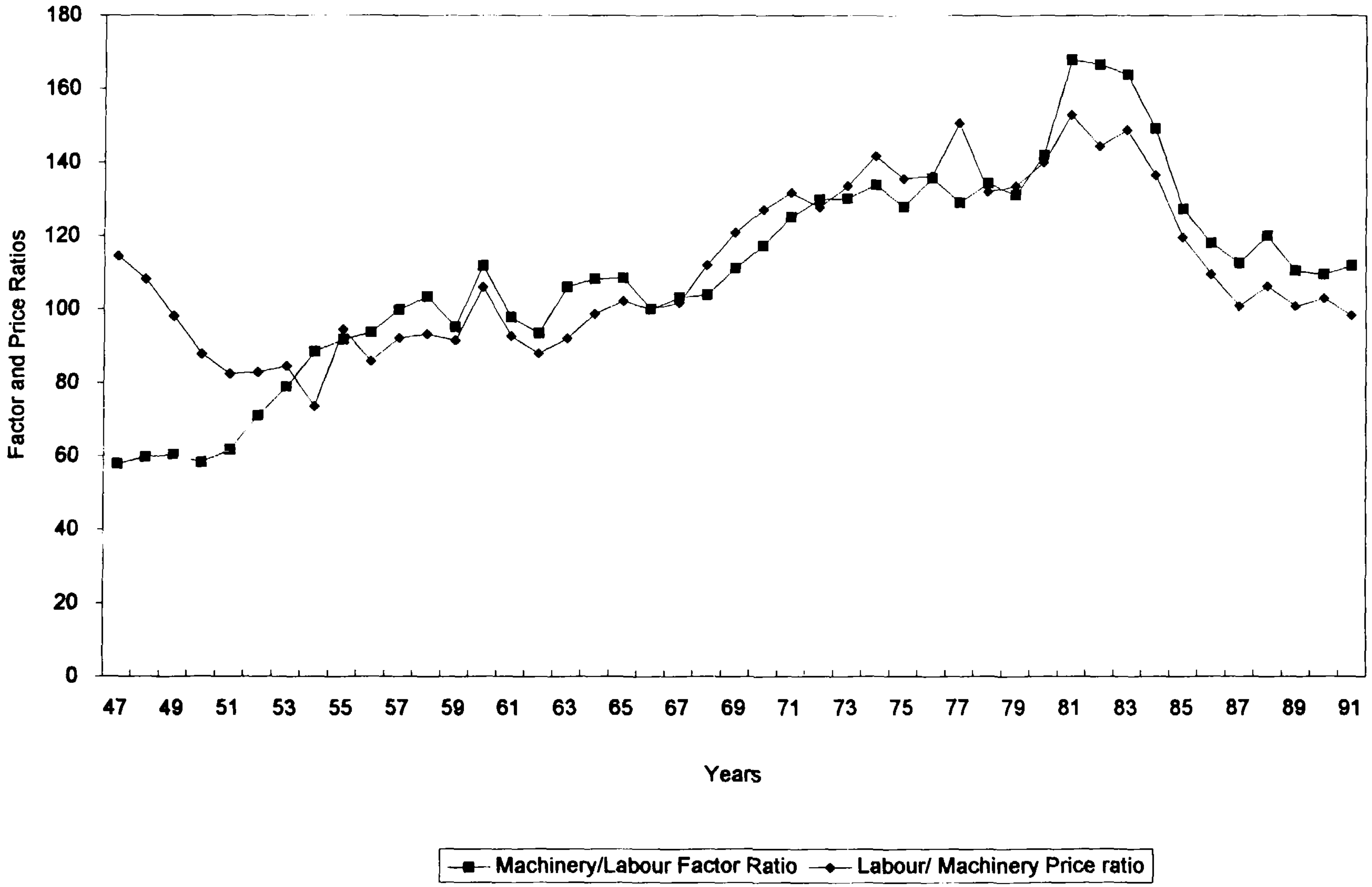

Figure 2 shows that the fertilizer/land factor ratios and price ratios are also highly correlated. The fit is not as close as for labour and machinery, but for the full period the R^2 was 0.87. There was some growth in land during the period 1947 to 1959, when the cultivated area was being expanded. 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. Finally, following the collapse of the gold price and devaluation of the Rand at the beginning of the 1980s, the land/fertilizer price ratio rises while the fertilizer/land ratio falls in 1981 and 1982[3]. This was the result of two years of severe drought. At the same time, agricultural subsidies and tax concessions ended and land rents fall relative to the price of fertilizer from 1984, with the factor ratio following the price ratio closely, with no lag. 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.

Adding the other relevant variables to the close relationships between the factor ratios and factor price ratios and taking logarithms gives OLS regression equations that can be estimated in the levels if cointegrating vectors exist. Following Frisvold (1991), the two equations are,

$$\ln(M/L)_t = \phi_1 + \sum_{t=t}^{t-j}\phi_2 \ln(P_M/P_L)_t + \sum_{t=1}^{t-k}\phi_3 \ln(P_A/P_L)_t + \sum_{t=1}^{t-l}\phi_4 lnRD_t + \sum_{t=1}^{t-m}\phi_5 lnMEP_t + \sum_{t=1}^{t-n}\phi_6 lnEXT_t + \sum_{t=1}^{t-o}\phi_7 lnSIZE_t + \phi_8 TAXD + \phi_9 INTD \quad (9)$$

$$\ln(F/A)_t = \delta_1 + \sum_{t=t}^{t-q}\delta_2 \ln(P_F/P_A)_t + \sum_{t=1}^{t-r}\delta_3 \ln(P_A/P_L)_t + \sum_{t=1}^{t-s}\delta_4 lnRD_t + \sum_{t=1}^{t-u}\delta_5 lnCHP_t + \sum_{t=1}^{t-v}\delta_6 lnEXT_t + \sum_{t=1}^{t-w}\delta_7 lnSIZE_t \quad (10)$$

M/L = machinery/labour factor ratio, P_M/P_L = machinery/labour price ratio, P_A/P_L = land to labour price ratio, P_F/P_A = fertilizer to land price ratio, RD = research expenditure, EXT = extension expenditure, SIZE = average farm size, TAXD = tax dummy, INTD= interest rate dummy, CHP = chemical patents, MEP = mechanical patents. All variables are in logarithms.

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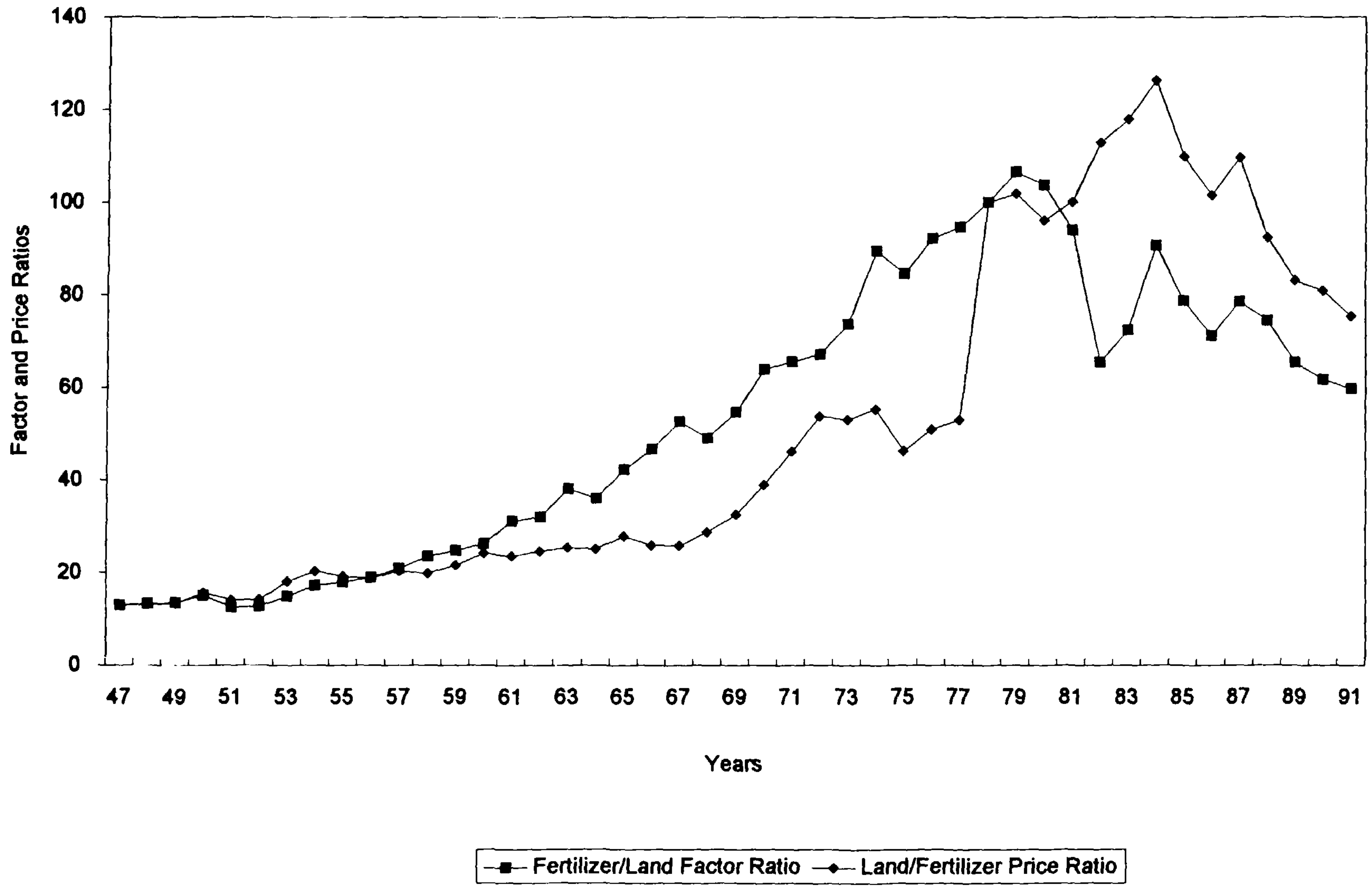
[3] The pattern of land prices and rents is explained in van Schalkwyk et al. (1994).

Figure 2: Correlation of Fertilizer/Land Factor and Price Ratios



Thus, the machinery/labour ratio is a function of past and present values of the machinery/labour price ratio and the land/labour price ratio, plus lagged values of public and private R&D, extension expenditures, farm size and the policy dummies for tax concessions and interest rates. Variable deletion tests reduced the list to the five variables reported in Table 2, meaning that extension, mechanical patents and farm size were not even jointly significant.

Table 2: Explaining Factor Ratios: OLS Regressions in the Levels

OLS: Dependent variable is Log Ratio Machinery/Labour: Adj R^2 = 0.924, DW = 1.63								
Variable	P_M/P_L	P_A/P_L	RD(-10)	TAXDUM	INTDUM		CRDW Test	DF Test
Coefficient t-statistic	-0.71 (-10.6)	0.12 (2.9)	0.10 (2.4)	0.09 (2.6)	0.006 (2.0)		1.63 (0.49)	-5.58 (-5.16)
OLS: Dependent variable is Log Ratio Fertilizer/Land, Adj R^2 = 0.949, DW = 1.56								
Variable	P_F/P_A	P_A/P_L	RD(-5)	CHP(-2)	SIZE	(P_F/P_A)MA	CRDW Test	DF Test
Coefficient t-statistic	-1.79 (-7.7)	-1.63 (-8.1)	0.42 (2.4)	0.18 (3.3)	-3.3 (-3.3)	-0.20 (-1.8)	1.56 (0.49)	-4.97 (-5.16)

Three tests for cointegration between combinations of variables were used; namely the DF test, the CRDW test and the Johansen procedure, which is further discussed below. Both the CRDW and DF tests suggest that the machinery/labour regression cointegrates and the more powerful Johansen procedure (reported in the next section) identified four cointegrating vectors. Thus, the relationship is not spurious, the fit is good and there is no serial correlation. The key variables are significant and the coefficients have the expected sign. The coefficient of the own price term (-0.71) is the direct partial elasticity of substitution. The positive sign on the land/labour price ratio conforms to Frisvold's (1991) expectation and suggests that machinery and land are substitutes. Public R&D has its greatest effect with a lag of ten years and both tax concessions on machinery purchases and negative interest rates increase the machinery/labour ratio.

The fertilizer/land equation also cointegrates according to the CRDW test and the Johansen method, which again identified four cointegrating vectors. The DF test indicates that the regression does not cointegrate, but the power of the test is too low to allow such a narrow failure to be taken seriously. The dummy variables were not significant, which is to be expected since the tax concessions and cheap credit affect machinery purchases far more than fertilizer use. The own price ratio coefficient of -1.79 indicates that considerable substitutability is possible between land and fertilizer. The negative sign on the land/labour price term indicates that fertilizer and labour are substitutes, which again matches Frisvold's (1991) theoretical expectation. Public R&D had a peak effect after a lag of five years and patents (representing private research) after two years. Large farms are less fertilizer-intensive and in this case lagged values of the own price ratio are significant. Indeed, a three year moving average (labelled $(P_F/P_A)MA$ in table 2) of past fertilizer/land prices was required to cure serial correlation.

These results suggest that these data corroborate the inducement hypothesis, although the coefficients of the land/labour price ratio are not easy to explain and the lag on public research should be longer in the fertilizer/land equation. The least satisfactory point is the lack of clear lagged effects in the machinery/labour equation, since the short run effect could more reasonably be called factor substitution. To improve on the levels regressions we progress to an ECM, which separates the short run changes from the long run equilibrium path. We tentatively identify the short run changes as factor substitution and the long run as induced technical change. The ECM also allows extensive tests of causality, which is the final stage in testing the inducement hypothesis.

AN ERROR CORRECTION MODEL AND TESTS FOR LONG RUN CAUSALITY

The maximum likelihood approach of Johansen (1988) and Johansen and Juselius (1990) allows estimation of all cointegrating relationships and tests for the number of cointegrating vectors and the direction of causality. The procedure begins by defining a VAR of a set of variables X,

$$X_t = \pi_1 X_{t-1} + \dots + \pi_k X_{t-k} + e_t \qquad t=1,\dots,T \qquad (11)$$

where if there are n variables, this becomes an n-dimensional k-th order vector autoregression model with Guassian errors. X_t is a vector of the n variables and k is large enough to make the error term white noise. The length of the lag can be determined by the Schwartz Criteria (SC). The VAR model can be reparameterized in error correction form (Cuthbertson et al 1993) as

$$\Delta x_t = \sum_{i=1}^{k-1} \Gamma_i \Delta x_{t-i} + \Pi x_{t-k} + e_t, \qquad t = 1,\ldots,T$$

$$where \Gamma = [(I+\pi_1),(I+\pi_1+\pi_2),\ldots,(I+\pi_1+..+\pi_k)]$$
$$\Pi = I-\pi_1-\pi_2-\ldots-\pi_k \tag{12}$$

and where I is the identity matrix. The Johansen testing procedure is a multivariate likelihood ratio test for an autoregressive process with independent Gaussian errors. It also decomposes Π into two matrices α and β both which are $n X r$, such that $\Pi = \alpha\beta'$, and the rows of β may be defined as the r distinct cointegrating vectors. That is, the cointegrating relationships between the n non-stationary variables, and the rows of α show how these cointegrating vectors are loaded into each equation in the system. The Johansen procedure uses maximum likelihood estimation techniques for estimating both matrices and uses trace and eigenvalue statistics to test for the number of cointegrating vectors.

Following equation (12) we can write the error correction model for the bivariate case as

$$\Delta y_t = \alpha + \sum_{i=0}^{r} \theta_i \Delta x_{t-i} + \sum_{i=1}^{s} \varphi_i \Delta y_{t-i} + \lambda_1 [y_{t-1} - \beta_1 x_{t-1}] + u_t \tag{13}$$

where θ captures the short run effect on y of the changes in x, and β_1 accounts for the long-run equilibrium relationship between y and x (the post-shock steady state). u_t is the disturbance term, with zero mean, constant variance and zero covariance. ($y_{t-1} - \beta_1 x_{t-1}$) is the divergence from long-run equilibrium, so λ_1 measures the speed at which the variables move back towards their relative long run equation levels after the shock (the extent of correction of such errors by adjustment in y). The long run relationship of x on y is derived as β_1/λ_1, which can be interpreted as the long run elasticity.

In the bivariate case x is said to Granger cause y if some lagged value of x is able to produce an improved forecast of y (Granger 1969). Several approaches are possible, but for the current purposes it is convenient to follow Hall and Wickens (1993) who use an error correction framework and distinguish between short run (transitory) and long run (permanent) causality. In this paper causality tests are performed on vector ECMs, such as the bivariate reparameterisation of (13)

$$\Delta x_t = \alpha + \sum_{i=0}^{p}\psi_i \Delta y_{t-i} + \sum_{i=1}^{q}\omega_i \Delta x_{t-i} + \lambda_2[x_{t-1} - \beta_2 y_{t-1}] + u_t \quad \textbf{(14)}$$

Variable deletion F-tests on equations (13) and (14) determine 'overall', 'short run' and 'long run' causality. Overall unidirectional causality form x to y is indicated if $\sum\theta_i,\lambda_1\beta_1\neq 0$ in equation (13) and if $\sum\psi_i,\lambda_2\beta_2=0$ in equation (14). x causes y in the short run, if $\sum\theta_i\neq 0$ and $\sum\psi_i=0$, and in the long run if $\lambda_1\beta_1\neq 0$ and $\lambda_2\beta_1=0$. An alternative causality test can be performed on the loading (long run) matrix. Using a Wald χ^2 test, there is unidirectional causality from x to y if $\lambda_1\neq 0$ in equation (13) and if $\lambda_3=0$ in equation (15).

$$\Delta y_t = \alpha + \sum_{i=0}^{m}\theta_i \Delta x_{t-i} + \sum_{i=1}^{n}\varphi_i \Delta y_{t-i} + \lambda_3[x_{t-1} - \beta_3 y_{t-1}] + u_t \quad \textbf{(15)}$$

Estimation of the ECM

Using the variables reported in Table 1 and employed in the levels regressions, reported in Table 2, the ECMs for the machinery to labour and the fertilizer to land factor ratio's are

$$\begin{aligned}\Delta\ln(M/L)_t = {} & \phi_0 + \sum_{t=t-1}^{t-i}\phi_1\Delta\ln(M/L)_t + \sum_{t=t}^{t-j}\phi_2\Delta\ln(P_M/P_L)_t + \sum_{t=1}^{t-k}\phi_3\Delta\ln(P_A/P_L)_t + \sum_{t=1}^{t-l}\phi_4\Delta lnRD_t \\ & + \sum_{t=1}^{t-m}\phi_5\Delta lnMEP_t + \sum_{t=1}^{t-n}\phi_6\Delta lnEXT_t + \sum_{t=1}^{t-o}\phi_7\Delta lnSIZE_t + \phi_8 TAXD + \phi_9 INTD \\ & + \lambda[\ln(M/L) - \alpha_1\ln(P_M/P_L) - \alpha_2\ln(P_A/P_L) - \alpha_3 lnRD - \alpha_4 lnMEP - \alpha_5 lnEXT - \alpha_6 lnSIZE]_{t-1}\end{aligned} \quad (16)$$

$$\begin{aligned}\Delta\ln(F/A)_t = {} & \delta_0 + \sum_{t=t-1}^{t-p}\delta_1\Delta\ln(F/A)_t + \sum_{t=t}^{t-q}\delta_2\Delta\ln(P_F/P_A)_t + \sum_{t=1}^{t-r}\delta_3\Delta\ln(P_A/P_L)_t + \sum_{t=1}^{t-s}\delta_4\Delta lnRD_t \\ & + \sum_{t=1}^{t-u}\delta_5\Delta lnCHP_t + \sum_{t=1}^{t-v}\delta_6 lnEXT_t + \sum_{t=1}^{t-w}\delta_7 lnSIZE_t \\ & + \lambda[\ln(F/A) - \beta_1\ln(P_F/P_A) - \beta_2\ln(P_A/P_L) - \beta_3 lnRD - \beta_4 lnCHP - \beta_5 lnEXT - \beta_6 lnSIZE]_{t-1}\end{aligned} \quad (17)$$

M/L = machinery/labour factor ratio, P_M/P_L = machinery/labour price ratio, P_A/P_L = land to labour price ratio, P_F/P_A = fertilizer to land price ratio, RD = research expenditure, EXT = extension expenditure, SIZE = average farm size, TAXD = tax dummy, INTD = interest rate dummy, CHP = chemical patents, MEP = mechanical patents.

The separable structure of the model implies that the machinery-to-labour ratio is determined independently of current prices of fertilizer and land and that the fertilizer-to-land ratio is determined independently of the current machinery price and the wage rate. In addition to public R&D and extension expenditures, chemical and mechanical patents registered by all countries in the US are again used to try and capture private research and international R&D spillovers. For the machinery/labour equation, dummy variables are included to capture the effect of tax concessions and negative interest rates. Farm size was used in the model to capture the biases caused by transaction costs for land and the costs of labour management, as suggested by de Janvry et al (1989).

Table 1 showed that all the variables are I(1), except for mechanical patents which may be trend stationary. Having established that the variables are integrated of the same order, cointegration tests were performed to determine long run relationships. Three tests were used to test for cointegration between combinations of variables, namely the DF test, the CRDW test and the Johansen procedure, as shown in Table 3.

Table 3: Cointegration tests

Equations tested	DF Test	CRDW Test	Johansen Model Eigenvalue Test Trace Test
M/L C P_M/P_L P_A/P_L RD SIZE TAXDUM INTDUM	-5.5 (-5.1)	1.5 (0.49)	1) 40.15 (34.4) 93.25 (76.07)
F/A C P_F/P_A P_A/P_L EXT CHP SIZE	-4.2 (-5.1)	1.2 (0.49)	1) 65.57 (40.3) 208.1 (102.1) 2) 48.19 (34.4) 142.6 (76.1) 3) 45.96 (28.1) 94.37 (53.1) 4) 27.72 (22.0) 48.41 (34.9)

Comparing the test statistics with the critical values (in brackets) shows that the machinery/labour equation cointegrates according to all three tests. Mechanical patents, which appeared to be I(0) was not significant and was dropped at this stage, as were extension expenditures. The fertilizer/land equation fails to cointegrate according to the DF test, but passes the CRDW test and the Johansen model[4] finds four cointegrating vectors, which indicates

[4] The maximum lag length of the VAR in the Johansen model was determined by the Schwartz Criteria, which indicates that the machinery/labour system has a VAR of one and the fertilizer/land system has a VAR of four. The results are relegated to Appendix 2, which can be disgarded later.

a strong and stable relationship between these variables. R&D and extension were collinear and in this case extension gave more significant results, which is sensible since the extension service recommended (excessive) fertilizer application rates over most of the period. The poor DW statistic for the second equation (CRDW in the table) is a reflection of the omitted dynamics rather than a long-run mis-specification.

Thus, there is a non-spurious long run relationship and the ECM is a valid representation (Engle and Granger, 1987). The results of the ECMs reported in Table 4 were chosen on the criteria of goodness of fit (variance dominance), data coherence, parameter parsimony and consistency with theory (Hendry and Richard 1982). The seemingly unrelated estimation procedure was used in order to gain efficiency in estimation, since the errors of the two equations were correlated.

Results

Only the significant coefficients are reported, in the interests of readability. 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 far more limited than the levels model suggested[5]. 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 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 indicates that a decrease in the machinery/labour price ratio generates labour-saving technological change. The error correction term for the machinery/labour equation is -0.71 which indicates that when the system is not in equilibrium, there is 71 percent

[5] Obviously, several of the parameter estimates can be compared with those for the levels model and most are of the same sign and similar magnitude.

correction towards the long run equilibrium level in the current period[6]. The positive sign on the land/labour price coefficient is of exactly the same value as in the levels regression reported in Table 2 and is in agreement with Frisvold's (1991) prediction. Lagged public R&D expenditures are positive and significant and the positive coefficient 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.

Table 4: Unrestricted ECM Results: *Significant* Variables Only

Variable	Coefficient	M/L Ratio	Coefficient	F/A Ratio
SHORT RUN				
CONSTANT	Φ_0	3.26 (3.5)	δ_0	-3.33 (-2.0)
$\Delta(P_M/P_L)_t$	Φ_2	-0.37 (-3.4)		
$\Delta(P_F/P_A)_t$			δ_2	-0.36 (-1.9)
$\Delta(P_A/P_L)_t$	Φ_3	NS	δ_3	-0.26 (-1.5)
TAXD	Φ_8	0.15 (2.5)		
INTD	Φ_9	0.09 (2.5)		
LONG RUN				
$(M/L)_{t-1}$	λ	-0.71 (-5.7)		
$(F/A)_{t-1}$			λ	-0.26 (-3.1)
$(P_M/P_L)_{t-1}$	$\lambda\alpha_1$	-0.34 (-2.1)		
$(P_F/P_A)_{t-1}$			$\lambda\beta_1$	-0.58 (-2.2)
$(P_A/P_L)_{t-1}$	$\lambda\alpha_2$	0.12 (2.9)	$\lambda\beta_2$	-0.45 (-2.2)
RD_{t-1}	$\lambda\alpha_3$	0.07 (1.4)		
CHP_{t-1}			$\lambda\beta_4$	0.12 (1.4)
EXT_{t-1}			$\lambda\beta_5$	0.15 (1.7)
$SIZE_{t-1}$	$\lambda\alpha_6$	0.21 (1.5)	$\lambda\beta_6$	-0.78 (-1.6)
R^2		0.66		0.42
DW		2.3		2.0

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

[6] Although the sign is correct and significant, the current period adjustment is too great.

The fertilizer/land model, did not perform as well in terms of explaining the deviations in the dependent variable, but an adjusted R^2 of 0.42 is reasonable high for an ECM. The short run coefficient on the fertilizer to land price ratio, of -0.36, is the direct partial elasticity of substitution, which is very much lower than the levels result in Table 2 and suggests that the short run substitution possibilities between land and fertilizer are very limited. The land/labour price ratio coefficient is negative and significant in the short run, suggesting that labour and fertilizer are substitutes.

In the long run, the error correction term for the fertilizer to land equation is -0.26. This indicates slow adjustment towards the long run equilibrium level in the current period, with full adjustment taking about four years. The negative sign shows that the direction of correction is towards equilibrium. The negative coefficient on the long-run own price variable 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 lagged patent variable, representing international technological spillovers is positive and significant and so is the effect of extension efforts. 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. The farm size variable in the fertilizer/land equation was large, negative and significant. A 10% decrease in farm size would increase the fertilizer/land ratio by 7.8% thus increasing the bias towards land-saving technological change.

Long Run Elasticities and Technological Change

Reference to equations (16) and (17) shows that the long run elasticities can be calculated from the results in Table 4 simply by dividing the long run coefficients by λ. Whereas the short run elasticities of substitution in Table 4 may be viewed as movements around isoquants, the long run equivalents calculated here would correspond to movements around innovation possibility surfaces, which encompass all the techniques which can be developed, given the state of scientific knowledge (see the discussion of Ahmed's model on page 2). If this meaning is attributed to the diseqilibria in the system, it implies that long run equilibrium is attained only after the innovations that have been induced by the changes in prices are adopted. These long run elasticities are reported in table 5.

Table 5: Long Run Elasticities for the ECM

VARIABLE	P_M/P_L	P_F/P_A	P_A/P_L	RD	EXT	CHP	SIZE
M/L EQUATION	-0.48	-	0.17	0.11	-	-	0.29
F/A EQUATION	-	-2.23	-1.73	-	0.58	0.46	-3.00

The high value of the adjustment coefficient for the machinery/labour equation means that the elasticity of substitution for the long run is only thirty percent greater than for the short run. The elasticity for the land/labour price, which was zero for the short run, is now 0.17 and a 10 percent increase in farm size will eventually increase the machinery/labour ratio by 2.9 percent. The elasticity of R&D suggests that in the long run R&D will shift the innovation possibility curve towards the origin by 11 percent.

The fertilizer/land results are more satisfactory, due to the lower adjustment coefficient of 0.26 (see Table 4). This gives a long run direct partial elasticity of substitution, around the innovation possibility curve, of -2.23. Similarly, the elasticity for the land/labour price is -1.73. In the long run, extension and chemical patents shift the IPC towards the origin by 46 and 58 percent respectively and farm size has a very large negative effect on the fertilizer land ratio. However, for South Africa, this effect results largely from the fact that the larger the farm, the greater the amount of ranching, relative to arable farming.

To corroborate the induced innovation hypothesis, the crucial requirement is that the coefficient for the lagged own-price term should be negative and significant, which is true in both models. The final stage is to apply causality tests to the ECM to ensure that is also true that the price ratios are Granger-prior to the factor ratios.

Causality

Causality tests within the ECM frame work can be conducted by applying variable deletion tests in the manner suggested in discussing equations (13) to (15) and/or by testing the loading matrix of the Johansen model for equations (16) and (17). If the change and levels terms for a variable cannot both be deleted according to the standard F test, then there is "overall causality", running from that variable to the dependent variable, or from left to right in Table A.1. Similarly, if the changes term alone cannot be deleted, there is "short run" causality and if the levels term alone cannot be deleted, there is "long run" causality. Again, the crucial test of the induced innovation hypothesis is that the causality must run from the long run price ratio to the factor ratio, as indeed it does. The long run causality also runs from the land/labour price to changes in the machinery/labour ratio and from R&D to changes in the price of machinery relative to labour. The loading matrix χ^2 tests confirm the causality from the price ratios to the factor ratios and indicate that the disequilibrium in the machinery/labour factor ratio does not feedback to prices, R&D or land size. This suggests that the price ratio's, R&D and farm size can be treated as weakly exogenous, which is consistent with the single equation model used here.

The direction of causality in the fertilizer/land system is more complex. The results again confirm the key point of the test, which is that the long run price ratios (for fertilizer/land and land/labour) are Granger-prior to the fertilizer/land factor ratio. However, the results from the loading matrix indicates feedback from the disequilibrium in the fertilizer/land ratio into extension expenditure and farm size. This suggests that extension and farm size are not weakly exogenous and hence that the single equation model may produce biased results. There are several other feedback effects of lesser importance and some of interest. For instance, the long run causality from the fertilizer/land price ratio to extension expenditures suggests that price changes lead farmers to demand technological changes.

CONCLUSION

This paper tests Hayami and Ruttan's (1985) induced innovation hypothesis using data 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 interest rates and tax concessions.

The use of cointegration methods allows the inducement hypothesis to be subjected to a series of tests. First, since the variables are non-stationary, the time series properties of the variables are determined to ensure that cointegration is possible. Then, 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. Finally, the ECM is subjected to causality tests to determine the direction of the long run relationships in the inducement mechanism. All of these tests corroborate the inducement hypothesis and the empirical results suggest 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.

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 must have influenced the allocation of R&D expenditures between labour and land-saving technical change. This will have 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. These results show that factor prices do matter in agricultural production and the selection of production technology, at least in South Africa. This is a clear indication that the usual policy prescription of the World Bank in many economies where prices are controlled and distorted, namely structural adjustment and market liberalization, has merit.

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Appendix One

Table A.1: Causality tests for the machinery/labour system

Dependent Variable	Variables deleted#	Short Run Causality	Long Run Causality	Overall Causality	Long Run Matrix Causality Tests
$\Delta(M/L)$	M/L	0.74	18.39**	11.09**	26.50**
	P_M/P_L	8.42**	4.83**	4.83**	21.53**
	P_A/P_L	0.58	6.31**	3.32*	9.30**
	RD	0.81	0.04	0.52	0.63
	SIZE	2.93	1.42	1.89	1.01
$\Delta(P_M/P_L)$	M/L	0.95	0.58	0.57	0.03
	P_M/P_L	1.00	1.06	1.62	0.31
	P_A/P_L	12.2**	0.83	6.30	2.65
	RD	0.27	5.83**	2.92	0.30
	SIZE	0.87	3.50	2.00	0.87
$\Delta(P_A/P_L)$	M/L	0.01	2.66	1.52	0.60
	P_M/P_L	12.16**	1.16	15.0**	0.37
	P_A/P_L	0.25	1.19	0.60	1.64
	RD	0.49	0.21	0.47	0.03
	SIZE	0.18	1.02	0.55	0.88
ΔRD	M/L	1.63	3.25	1.88	0.36
	P_M/P_L	0.27	4.13	2.11	1.41
	P_A/P_L	0.49	0.35	0.37	0.38
	RD	0.78	0.17	0.82	1.19
	SIZE	0.83	0.69	0.66	1.80
$\Delta SIZE$	M/L	0.19	0.36	0.45	0.36
	P_M/P_L	0.87	0.08	0.70	0.03
	P_AP_L	0.18	0.61	0.36	0.76
	RD	0.83	0.21	0.44	0.19
	SIZE	0.37	0.65	0.67	0.88
Critical Values (95%)		3.37	4.23	2.98	3.84

The difference terms and the levels terms were deleted indivdually and together for the short run, long run and overall causality tests respectively. For the long run matrix test the variables deleted indicate the disequilibrium variable in the loading matrix.

** Significant at the 95% confidence level.

Table A.2: Causality test for the fertilizer/land system

Dependent Variable	Variables deleted†	Short Run Causality	Long Run Causality	Overall Causality	α-Matrix Causality
Δ(F/A)	F/A	0.24	8.90**	5.52**	10.53**
	P_F/P_A	3.56**	8.63**	3.60**	8.38**
	P_A/P_L	2.93	9.11**	3.55**	13.59**
	RD	2.85	0.19	1.96	0.21
	CHP	1.96	10.33**	3.75**	9.14**
	EXT	0.31	0.13	0.52	0.14
	SIZE	0.42	3.61	1.12	5.06
$\Delta(P_F/P_A)$	F/A	1.06	1.40	0.80	1.15
	P_F/P_A	0.75	4.56**	6.00**	7.01**
	P_A/P_L	44.24**	1.68	29.51**	2.62
	RD	1.64	0.16	1.15	0.01
	CHP	2.65	0.06	1.94	0.37
	EXT	0.02	0.01	0.24	0.01
	SIZE	4.21**	2.21	3.31**	3.57*
$\Delta(P_A/P_L)$	F/A	0.64	1.57	0.79	0.66
	P_F/P_A	46.58**	4.13	33.57**	4.37**
	P_A/P_L	2.57	5.73**	2.41	3.29
	RD	1.43	0.02	1.10	0.33
	CHP	3.67**	0.01	2.88	0.22
	EXT	0.19	0.54	0.20	0.29
	SIZE	3.49**	1.48	2.53	2.33
ΔCHP	F/A	0.33	0.48	0.27	0.01
	P_F/P_A	0.41	1.15	0.64	0.67
	P_A/P_L	0.12	1.65	1.39	1.35
	RD	1.27	0.68	0.94	0.04
	CHP	3.67**	2.36	5.31**	3.73*
	EXT	0.58	0.40	0.39	0.01
	SIZE	1.01	0.02	0.73	0.01
ΔEXT	F/A	0.22	4.42**	2.55	4.38**
	P_F/P_A	0.07	6.06**	3.02**	5.49**
	P_A/P_L	0.11	8.74**	4.69**	6.39**
	CHP	2.24	3.17	2.33	0.53
	EXT	5.69**	6.10**	10.90**	3.01
ΔSIZE	F/A	13.36**	8.43**	7.94**	6.63**
	P_F/P_A	3.82**	0.62	2.55	0.46
	P_A/P_L	3.89**	4.09**	3.61**	4.62**
	RD	0.46	2.07	0.76	1.70
	CHP	2.13	0.10	1.43	0.12
	EXT	0.11	0.24	0.27	0.01
	SIZE	0.05	10.52**	5.26**	8.09**
Critical values		3.39	4.24	2.99	3.84

The difference terms and the levels terms were deleted indivdually and together for the short run, long run and overall causality tests respectively. ** Significant at the 95% confidence level. * Significant at the 90% confidence level.

Appendix Two

Table A.3: Testing the VAR length for the machinery/labour system.

Variable	MLL(1)	MLL(2)	MLL(3)	MLL(4)
M/L	62.35	65.34	72.36	75.71
P_M/P_L	52.95	55.19	61.28	65.26
$P_{A/P}L$	27.69	28.38	31.15	38.86
RD	44.69	47.68	54.68	57.93
SIZE	98.10	99.35	104.94	112.24
TOTAL	285.78	295.94	324.41	349.50
Schwartz Crit.	253.96**	244.23	252.81	251.63

** Largest Value

Table A4: Testing for cointegration using the Johansen Maximum Likelihood procedure: The machinery/labour equation

Maximal Eigenvalue Test : VAR = 1;				
Null	Alternative	Statistic	95% Critical Values	90% Critical Values
r = 0	r = 1	40.15	34.40	31.66
r<= 1	r = 2	25.34	28.13	25.56
r<= 2	r = 3	19.26	22.00	19.77
r<= 3	r = 4	6.85	15.67	13.75
r<= 4	r = 5	1.65	9.24	7.53

Trace Statistic : VAR = 1;				
Null	Alternative	Statistic	95% Critical Values	90% Critical Values
r = 0	r>= 1	93.25	76.07	71.86
r = 1	r>= 2	53.10	53.17	49.65
r<= 2	r>= 3	27.77	34.91	32.00
r<= 3	r>= 4	8.50	19.96	17.85
r<= 4	r>= 5	1.65	9.24	7.53

Table A.5: Testing the VAR length for the fertilizer/land equation

Variable	MLL(1)	MLL(2)	MLL(3)	MLL(4)
F/A	38.47	41.51	50.25	52.74
$P_{F/P}A$	30.02	34.54	38.40	44.75
$P_{A/P}L$	26.29	28.26	36.84	40.19
EXT	50.00	61.09	67.24	78.69
CHP	15.46	23.17	34.20	41.43
SIZE	96.44	110.78	123.90	137.00
TOTAL	256.68	299.35	350.83	394.80
Schwartz Crit.	228.81	247.64	275.25	295.35**

** Largest Value.

Table A.6: Testing for cointegration using the Johansen Maximum Likelihood procedure: The fertilizer/land equation.

Maximal Eigenvalue Test : VAR = 4;			
Null Alternative	Statistic	95% Critical Values	90% Critical Values
r = 0 r = 1	65.57	40.30	37.44
r<= 1 r = 2	48.19	34.40	31.66
r<= 2 r = 3	45.96	28.14	25.55
r<= 3 r = 4	27.72	22.00	19.77
r<= 4 r = 5	13.27	15.67	13.75
r<= 5 r = 6	7.42	9.24	7.53

Trace Statistic : VAR = 4;			
Null Alternative	Statistic	95% Critical Values	90% Critical Values
r = 0 r>= 1	208.13	102.14	97.18
r = 1 r>= 2	142.56	76.07	71.86
r= 2 r>= 3	94.37	53.12	49.65
r<= 3 r>= 4	48.41	34.91	32.00
r<= 4 r>= 5	19.50	19.96	17.85
r<= 5 r>= 6	7.42	9.42	7.53

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