

MACHINERY AND LABOUR BIASES OF TECHNICAL CHANGE IN SOUTH AFRICAN AGRICULTURE: A COST FUNCTION APPROACH

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This paper provides an empirical investigation into the long-standing notion of biases of technical change in South African agriculture. The second order cost function is used to derive relative bias measures between labour and machinery. The results suggest that large machinery-using biases in technology have been developed with minimal labour-using biases.

MASJIENERIE- EN ARBEIDSVOORKEURNEIGINGS IN TEGNIESE VERANDERING IN DIE SUID-AFRIKAANSE LANDBOU : 'N KOSTEFUNKSIEBENADERING

Hierdie referaat verskaf 'n empiriese ondersoek na die langstaande opvatting van voorkeurneigings in tegniese verandering in die Suid-Afrikaanse landbou. Die tweede orde kostefunksie word gebruik om relatiewe voorkeur metings tussen arbeid en masjienerie te bepaal. Die resultate impliseer dat groot masjienerie-gebruikende voorkeurneigings in tegnologie, met minimale arbeids-gebruikende voorkeurneigings, ontwikkel het.

1. INTRODUCTION

Since Hicks (1932), the notion of biases of technical change has received much attention in the literature (for example, Binswanger, 1974; Blackorby *et al*, 1976; Stevenson, 1980; Antle & Capalbo, 1988). According to Hicks, techniques designed to facilitate the substitution of other inputs for labour in production are 'labour-saving technologies'. In agriculture this generally means mechanical technology. This paper examines technical change in South African agriculture with specific focus on whether technologies developed have been machinery or labour-using. A cost function approach will be used in the analysis. This approach is described in the next section. As time series data are used in the analysis, the time-series properties of the variables are established to determine the appropriate representation of the technology variable. The Kako decomposition method is then used to derive biases of technical change

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between machinery and labour.

2. THE COST FUNCTION APPROACH

The cost function is a common approach used to measure the bias of technical change (Binswanger, 1974; Kako, 1978; Stevenson, 1980; Archibald & Brandt, 1991; and Machado, 1995). Allowing for the possibility of quasi-fixity in inputs, a temporary equilibrium framework can be formulated and the variable cost function can be expressed as the minimisation of

$$cv = cv(w, Z, Y) \tag{1}$$

where w is the vector of variable input price, Z is a vector of quasi-fixed and fixed inputs and Y is the vector of output levels. A common functional form used in cost function analysis is the transcendental logarithmic (translog) form which is considered to be a flexible representation of the production system and underlying technology. Functions that provide second-order numerical or differential approximations to some unobservable underlying function are called flexible functional forms.

The second-order translog form for m outputs, n inputs, k fixed and quasi-fixed inputs and an index of technology t is specified as

$$\begin{aligned} \ln CV = & \alpha_0 + \sum_i^m \alpha_{Y_i} \ln Y_i + \sum_i^n \alpha_i \ln w_i + \sum_i^k \beta_i \ln Z_i \\ & + \frac{1}{2} \sum_i^m \sum_i^m \gamma_{ij} \ln Y_j \ln Y_j + \frac{1}{2} \sum_i^n \sum_i^n \gamma_{ij} \ln w_j \ln w_j + \frac{1}{2} \sum_i^k \sum_i^k \delta_{ij} \ln Z_j \ln Z_j \\ & + \sum_i^m \sum_i^n \rho_{ij} \ln Y_j \ln w_j + \sum_i^n \sum_i^k \rho_{ij} \ln w_j \ln Z_j + \sum_i^n \sum_i^k \Pi_{ij} \ln Y_j \ln Z_j \\ & + \phi_t + \frac{1}{2} \phi_{tt} + \sum_i^m \phi_{Y_it} \ln Y_i + \sum_i^n \phi_{wt} \ln w_i + \sum_i^k \phi_{Z_it} \ln Z_i + e_t \end{aligned} \tag{2}$$

and the associated input share equations are⁴;

$$S_i = \alpha_i + \sum_j \gamma_{ij} \ln w_j + \sum_j \rho_{ij} \ln Y_j + \sum_j \rho_{ij} \ln Z_j + \phi_{it} + e_i, \quad i = 1, \dots, n \tag{3}$$

⁴ The share equations are derived as the partial derivatives of the variable cost function with regard to input prices. The implicit demand functions are Hicksian (output-compensating).

and the output share equations (where the share of output i is given as the value of output i over variable costs)⁵;

$$S_i = \alpha_i + \sum_i^n \rho_{\gamma_{ij}} \ln w_j + \sum_i^m \gamma_{ij} \ln Y_j + \sum_j^k \Pi_{ij} \ln Z_j + \phi_{it} + e_i, \quad i = 1, \dots, m \quad (4)$$

The national farm-level production data for the period 1947-91 is described in some detail in Thirtle *et al.* (1993). These data are also used in this analysis. One division aggregated output group and four variable input groups were used in the analysis. The inputs were labour, machinery, fertiliser and miscellaneous inputs. The quasi-fixed inputs used were land, capital (fixed capital in the form of buildings and other formal improvements) and livestock capital (stocks of animals).

Prior to estimation of the cost function, the time-series properties of the variables need to be examined to avoid possible spurious regressions arising with trended data. Technology in equation (2) is represented by a time-trend. This representation has been common to many studies (Binswanger, 1974; Stevenson, 1980). This may lead to OLS coefficient estimates that will be inefficient. Significance levels will be inflated and there will be a high probability of concluding that there is a significant relationship among the variables when, in fact, no relationship exists (Clark & Youngblood, 1992). If the variables are, however, integrated of order one, then cointegration among the variables implies that technical change is neutral.

3. DETERMINING HICKS NEUTRAL TECHNICAL CHANGE

Clark and Youngblood show a more general specification of the factor shares in equation (3) as

$$S_i = \alpha_i + \sum_i^n \gamma_{ij} \ln w_j + \sum_i^m \rho_{\gamma_{ij}} \ln Y_j + \sum_j^k \rho_{z_{ji}} \ln Z_j + a_{it} + e_i \quad i = 1, \dots, n \quad (5)$$

where a_{it} is the factor specific technological change stochastic process. If a_{it} is omitted due to the absence of a direct measure of technical change, then the error term will become $(a_{it} + e_t)$ in equation (5). The technical change bias can then be determined for the i th factor to be:

- 1) factor i using if $\Delta a_{it} > 0$,

⁵ These are derived (in a similar manner to the variable input share equations) as the derivatives of the cost function in respect of output levels.

- 2) neutral if $\Delta ait=0$,
- 3) factor i saving if $\Delta ait < 0$.

The statistical properties of Sit in equation (5) can suggest different technical change biases:

- i) Sit is stationary around a linear deterministic time-trend and all elements of w and Z are stationary. In this case $ait = bit + eit$, where t is the time-trend and eit is white noise.
- ii) Both Sit and all the elements of w and Z contain a single unit root. Following this, the variables may be:
 - cointegrated of order (1,1). In this case the error term, and hence ait is stationary, thus representing neutral technical changes.
 - non-cointegration exist between the variables. Thus, ait is $I(1)$, resulting in technical change bias.

In order to investigate the time-series properties of the data for South Africa, the four-branch decision tree represented in Table 1 of Clark & Youngblood (1992:356) is used. Two of the four factor shares can be adequately represented by a trend stationary process, together with the labour, machinery, miscellaneous prices and the output variable. The fertiliser and machinery share equations and the quasi-fixed inputs follow a random walk, with fertiliser price being represented by a random walk with drift. As two of the four factor share variables are trend stationary, together with two of the factor prices, the use of a time-trend to capture technical change effects can be regarded as a reasonable approximation to the correct (unknown) duality model (Machado, 1995). Thus, the traditional equation (3) and (4) are used for estimation.

These share equations were estimated using the iterative Zellner procedure. The symmetry condition follows from the assumption of twice continuous differentiability of the cost function in prices. Symmetry requires $\gamma_{ij} = \gamma_{ji}$. Similarly, symmetry is imposed on the quasi-fixed and fixed input coefficients ($\delta_{ij} = \delta_{ji}$). The theoretical requirement of linear homogeneity of the cost function in prices implies the following constraints:

$$\begin{aligned}
 \sum_{i=1}^n \alpha_i &= 1; \quad \sum_{i=1}^n \phi_{it} = 0, \\
 \sum_{i=1}^n \gamma_{ij} &= \sum_{i=1}^n \gamma_i = 0, \quad j = 1, \dots, m \\
 \sum_{j=1}^n \rho_{Yij} &= 0, \quad \sum_{j=1}^n \rho_{Lij} = 0, \quad i = 1, \dots, m
 \end{aligned} \tag{6}$$

The representation of technology with a time-trend allows the derivation of the appropriate indices of biased technical change. Binswanger (1974) derived a bias measure in his analysis of US agriculture that captured the effects of technical change on factor shares which can be expressed as

$$B_i^c(Y, W, t) = \frac{\partial \ln S_i(Y, W, t)}{\partial t} \tag{7}$$

‘Constant price factor shares’ were used to derive indices of factor-using technical change bias which were derived *residually* as the shares that would have existed in the absence of factor price changes. Equation (7) can be written as

$$B_i^c(Y, W, T) = \frac{\partial \ln X_i(Y, W, T)}{\partial T} - \sum_{j=1}^n S_j \frac{\partial \ln X_j(Y, W, T)}{\partial T} \tag{8}$$

Following Machado (1995) the right-hand side terms may be interpreted as:

- (i) the proportional variation in input use due to technical change;
- (ii) the proportional variation of the (Tornqvist-Theil) index of aggregate input use due to technical change.

Thus, this equation provides an indication of how technical change affects the ratio between the quantities of input *i* and an aggregate measure of all inputs over time. In this analysis, a biased measure that is equivalent to Binswanger’s constant price factor share indices is calculated using the Kako decomposition (1978).

4. THE KAKO DECOMPOSITION

This section follows the approach of Kako (1978), which is used by Machado (1995). Under cost-minimising behaviour, the equilibrium quantity demanded is given as:

$$X_i = F(Y, W, T) \quad i = 1, \dots, n \quad (9)$$

Differentiating this expression yields

$$\partial \ln X_i = \frac{\partial \ln X_i}{\partial \ln Y} \partial \ln Y + \sum_j \frac{\partial \ln X_i}{\partial \ln W_j} \partial \ln W_j + \frac{\partial \ln X_i}{\partial \ln T} \partial \ln T \quad (10)$$

The first term on the right-hand side represents the output effect on the change in demand, the second term represents the substitution effect of a change in demand and the last term represents the technical change effect on a change in demand for a particular factor of production. The first two effects from the translog cost function can be represented as:

$$\frac{\partial \ln X_i}{\partial \ln Y} \partial \ln Y = \frac{\rho_{Yi}}{S_i} + R_Y \cdot \partial \ln Y \quad (11)$$

which is the *output effect*, where R_Y can be approximated by the ratio between output value and total cost, and

$$\sum_j \frac{\partial \ln X_i}{\partial \ln W_j} \partial \ln W_j = \sum_j S_j \sigma_{ij} \partial \ln W_j \quad (12)$$

which is the *substitution effect*. σ_{ij} is the Allen partial elasticity of substitution between input i and j .

The technical change effect can then be determined *residually* by rearranging and subtracting the estimated output and substitution effects in equation (10). The resulting *residual effect* reflects the percentage variation in the use of input i which was caused by technical change.

$$\frac{\dot{X}_i^{TC}}{X_i^{TC}} = \frac{\partial \ln X_i}{\partial \ln T} \partial \ln T \quad (13)$$

Indices of input use due to technical change could then be derived. These are then aggregated via the common Tornqvist-Theil approximation to the divisia index, resulting in an index of aggregate input use due to technical change, XTC. Finally the absolute measures of technical change bias can be derived as

$$B_i = \frac{X_i^{TC}}{X^{TC}} \quad (14)$$

This bias measure can be interpreted as an index of relative (to all) factor use due to technical change.

5. ESTIMATION AND RESULTS

The system of share equations (3) and (4) were estimated as a seemingly unrelated system, without the miscellaneous input share, to avoid singularity, and subject to the restrictions of symmetry and homogeneity. Thus, there are three input share equations, namely for labour, machinery and fertiliser, and one output share equation for aggregate output. The parameters derived solely from the share equations allow tests of all the theoretical consistency conditions. The theoretical properties of the variable cost function are non-decreasing in variable factor prices, non-increasing in quasi-fixed factors, non-decreasing in output, homogeneous of degree one in variable factor prices, symmetric in the Hessian of variable factor prices, concave in variable factor prices, convex in quasi-fixed factors and convex in output quantities (Khatri, 1994). Tests indicated that these theoretical properties were satisfied by the model. Thus, there is a good expectation of the cost function being well behaved in respect of inputs, outputs and quasi-fixed inputs. The corresponding machinery and labour biases of technical change were then computed. The resulting indices of relative factor biases for machinery and labour are compared graphically in Figure 1.

These indices do not vary, as the indices derived for the US by Binswanger (1974), and are more consistent with those derived by Machado (1995). The results should be treated with caution as, with all *residual* based tests, there could be some unaccounted noise which has been included in the technical change bias value which may distort the results. This spillover effect is likely to be present in the current estimates due to the important influence of the exogenous variables described in the previous section. Nevertheless, these results provide some consistency with the results derived in other studies (see Townsend & Thirtle, 1996), showing that technology developments have been more machinery using relative to labour due to technical change. This bias is mostly positive, especially from 1960 to 1987. The decline in 1987 coincides with the removal of the policy distortions favouring mechanisation.

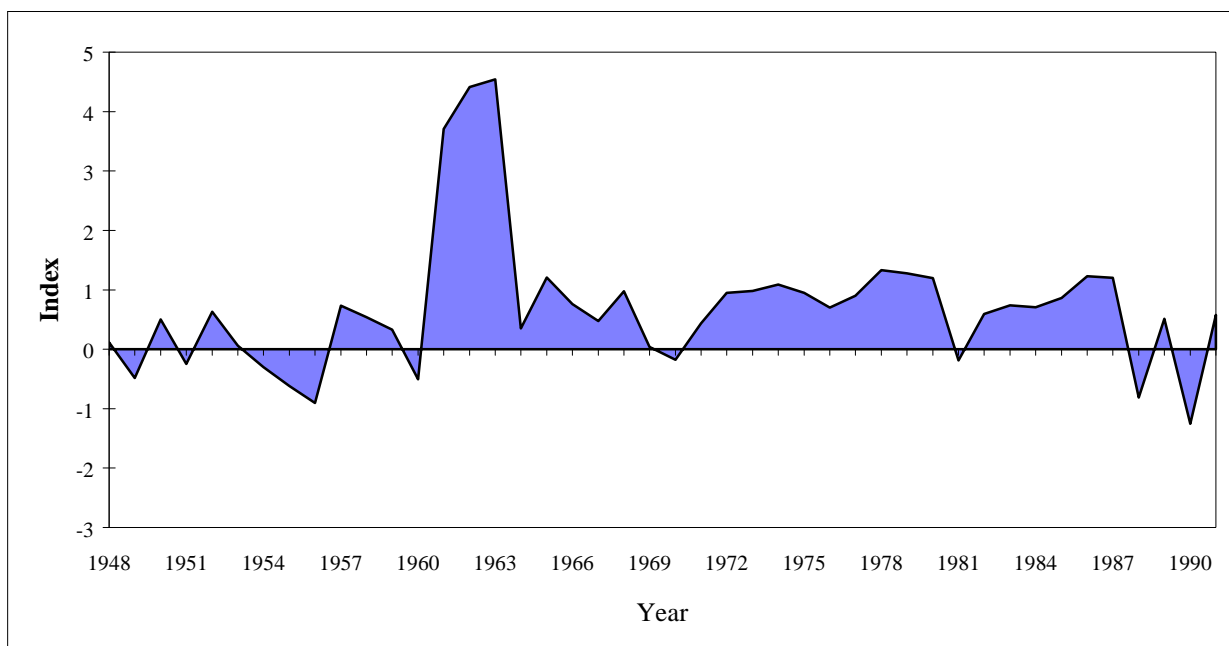


Figure 1: Index of relative technical change bias between machinery and labour

6. CONCLUSION

This paper has attempted to provide some empirical investigation into the long-standing notion of biases of technical change in South African agriculture. The second order cost function is used to derive relative bias measures between labour and machinery. The results suggest that large machinery-using biases in technology have been developed with minimal labour-using biases. These biases have not contributed to alleviating the unemployment problem currently faced in the labour-surplus economy of South Africa. The biases have largely been caused by policies favouring the large-scale capital-intensive production model. With removal of these biased policies, the bias of technical change towards machinery-using technology should be reduced.

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