REVIEW OF MARKETING AND AGRICULTURAL ECONOMICS
Vol. 45, No. 4 (*December*, 1977)

# ESTIMATION OF TECHNOLOGICAL CHANGE IN THE PASTORAL ZONE

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Measurement of rates of technological change is frequently done in the context of the production function. While measurement suffers problems ranging from conceptual to statistical, this study focuses on the dependence of measurements on the algebraic form of the function specified and the statistical approach adopted. The data relate to an individual property in the central western Queensland sheep country.

## 1 INTRODUCTION

Technological change that is postulated to be neutral and at a constant rate over time, makes for the simplest possible measurement from an analytical point of view [2]. Different algebraic models impose different restrictions on the final estimates of parameters of economic interest—including those describing technological change.

This study examines the hypothesis that estimates of technological change (a) depend importantly on the form of production function deployed, and (b) are sensitive to the estimating techniques used. Interest in this hypothesis was sparked by a question in our minds about the robustness of estimates of technological change in the New South Wales pastoral zone reported by Duncan [4].

The data analysed are from a single sheep grazing property in the semiarid Queensland pastoral zone. This avoids both the conceptual and empirical problems of dealing with cross-sectional data. The chief analytical advantage of choosing such a relatively uncomplicated mode of production for study, is that output is reasonably well-represented by the easily measured and well-recorded statistic, wool production. Second, the generally unsophisticated methods of production have not changed drastically over the decades suggesting that the usual aggregation of factor inputs to "labour" and "capital" components may in this instance be a tolerable empirical simplification.

Technological change is probably seldom constant or neutral over time. However, measurement of non-constant, non-neutral technological change is not really feasible with present-day statistical procedures. Thus the

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present study concentrates on estimational procedures that imply that technological change is constant and "Hicks neutral" over time. This means that, with given factor proportions, the technological change postulated changes the marginal products of labour and capital by the same proportion. While clearly being a very restrictive assumption [9, 12], this is the concept most frequently used in empirical work and, in particular, is the one used by Duncan [4] in the study to which the present one is most directly linked.

## 2 DATA

The study property was chosen primarily because its records contained a long series of relevant information—including rainfalls, number of sheep shorn, average clip weight, price received for wool, and the number of employees—for the 34 years, 1937 to 1970. A detailed record of fixed improvements, including dams, bores, fences, buildings and sheepyards had been kept since 1900. Not only were the initial costs of the improvements available but so also were the costs of repairs to, and maintenance on these improvements. A series for stockman's wages was obtained from the Queensland *Government Gazette*.

Annual capital purchases were deflated[1] and converted to a flow of services. It seems reasonable to assume that the flow of services from dams, bores and fences is approximately constant over time, and that such assets have zero salvage value at the end of their life. These assumptions permit the use of Yotopoulos' [19] formula for converting capital stocks to flows. The formula is not very sensitive to the rate of discount or the life of the asset. The assumed 30-year life of a fence was taken as the life expectancy for each new capital expenditure. This simplifying assumption will cause a slight upward bias in the implied service flows from assets with life spans exceeding 30 years. The trading bank overdraft rate of interest [15] was taken as the appropriate discount rate.

The values of land, livestock and plant and machinery were not included in the capital series. Land was not included because the service flow from land seems unlikely to have changed systematically over time. Livestock values were not included on the presumption that in this context livestock is essentially an output from the productive process. Flows of services from plant and machinery would certainly have been included in the capital series had details on them been available. Both the quantity and value of plant and machinery have doubtlessly increased over the period under consideration, thus making a potentially important contribution to output. Moreover, the increasingly sophisticated nature of machinery is likely to have contributed to any technological change that may have taken place. The omission of these three factors may be an important limitation to the validity of any conclusions about rates of technological progress but will probably not crucially influence the methodological core of the study.

[1] A deflating index for the period 1900 to 1970 was constructed by splicing indexes of (a) the purchasing power of money in metropolitan towns; (b) the "C" Series Index; and (c) the Consumer Price Index.

The cost of capital service flow is the flow plus the opportunity cost of not investing elsewhere. The conservative estimate of the opportunity cost of investing in fixed improvements that is added here is the bank overdraft rate of interest. To summarize, the other variables are as follows: $Y_W$ = output expressed as weight of wool produced (lb per year), $Y_S$ = output expressed as number of sheep shorn, $L$ = labour (number of employees per year), $K$ = capital service flow ($ per year), $W$ = wage rate ($ per employee per year), $P$ = price received for wool sold ($ per lb), $R$ = annual rainfall (inches), and $t$ is a time trend variable (for 1937, $t = 1$).

## 3 METHODS

Least squares regression analysis was used to estimate a variety of alternative forms of production functions. Two of these, by dint of extensive empirical application, must be judged as standard functions, namely the Cobb Douglas [7, 13] and the Constant Elasticity of Substitution (CES) [1, 2, 7] functions. Less restrictive models of production have also been developed and of these the Variable Elasticity of Substitution (VES) [11, 16] functions and members of the class of Generalized Power Production Functions (GPPF) [3], including the Transcendental Function [6], have also been compared in this exercise.

Linear estimation of CES and VES functions has to make use of various "side relations" derived by making some strong assumptions about efficient resource use under perfectly competitive conditions. Since these techniques involve some cumbersome derivations and are well-described in many other places (especially [2, 11]) we do not elaborate them here. The results presented were obtained by applying these techniques and exercising some statistical judgments about the eventual inclusion of possible explanatory variables on the basis of their statistical and economic significance.[2]

Specification errors which unavoidably occur in the empirical application of the side relations of the CES functions [14] may lead to biased estimates. Bias in estimates will contribute to the variation between estimates obtained by using different estimating functions.

A problem of frequent importance in fitting functions to time-series data is that of non-independence of error terms. Several alternative procedures have been suggested for dealing with this problem under the assumption that the autocorrelation is first order only [8, 18]. We also examine the effect of two alternative methods of "correcting" for non-independence on estimates of the rate of technological change.

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[2] By way of illustration, the original estimating equation for the selected GPPF was $\widehat{lnY_W} = a + \hat{\lambda}t + b_1 lnK + b_2 LlnK + b_3 RlnK + b_4 lnL + b_5 KlnL + b_6 KlnR + b_7 lnR + b_8 KlnR + b_9 LlnR + b_{10} L + b_{11} K + b_{12} R$, where $t$ denotes a time trend and the other variables are as defined at the end of section 2 with time subscripts being here understood. The constant neutral rate of technological change is estimated in this model by the second regression coefficient (i.e., the coefficient on the time variable).

## 4 RESULTS

The considerable volume of uninteresting statistics generated in a methodological study of technological change involving a diversity of alternative models, poses a reporting problem. In the interests of brevity we have chosen to report only a concise and "insufficient" subset of statistics that directly pertains to the hypothesis under review.[3]

In Table 1 we compare measurements conditional on several alternative production functions and, where relevant, alternative side relations invoked to linearize the estimations. A range of values for the estimated rate of technological change is evident, namely from −0.0167 for the CES capital side relation to −0.0011 for the VES capital side relation. However, to our surprise, the rate of change is consistently indicated as being negative. In percentage terms, these estimates range from approximately zero (i.e., −0.11 per cent) to −1.67 per cent. This latter "high" negative value contrasts with Duncan's [4, p. 27) estimate of +1.31 per cent for a comparable pastoral region in New South Wales. The coefficients of multiple determination are reported here only to provide a suggestion of the statistical quality of each individual regression and should not be used to judge comparative merits of the alternative functions since, in some models, different dependent variables are employed. In all these cases output is measured by wool produced.

TABLE 1: *Rates of Technological Change and Some Pertinent Statistics Assessed Using Alternative Production Functions*

| Function and method of estimation | Rate of technological change | $t^a$ | $\bar{R}^{2\,b}$ | D-W |
|---|---|---|---|---|
| CES Capital side relation .. .. | −0.0167 | —$^c$ | 0.17 | 1.04 |
| CES Labour side relation .. .. | −0.0110 | —$^c$ | 0.22 | 1.93 |
| CES Substitution side relation (Brown) | −0.0035 | 0.85 | —$^d$ | —$^d$ |
| CES Taylor series (Kmenta) .. .. | −0.0026 | 0.78 | 0.23 | 2.28 |
| VES Capital side relation .. .. | −0.0011 | —$^c$ | 0.90 | 2.03 |
| VES Labour side relation (Lu and Fletcher) .. .. .. .. | −0.0118 | —$^c$ | 0.77 | 2.03 |
| Cobb Douglas .. .. .. .. | −0.0037 | 0.97 | −0.01 | 1.84 |
| Transcendental .. .. .. | −0.0051 | 1.35 | 0.04 | 1.98 |
| GPPF$^e$ .. .. .. .. .. | −0.0058 | 1.65 | 0.28 | 2.17 |

[a] The $t$ test statistic for the null hypothesis that the rate of technological change is zero (approximately 30 degrees of freedom).

[b] Generally, adjusted coefficients of multiple determination cannot be compared validly between equations.

[c] Rate of technological change here is estimated as a function of two regression coefficients so simple $t$ test is not applicable.

[d] Meaningless measures in a two-stage estimational procedure.

[e] This is the only function in this table that includes a rainfall variable. The form of GPPF selected is $Y_W = \beta_0 \exp(\lambda t + \beta_1 K + \beta_2 L + \beta_3 R)(K^{\beta_4 + \beta_5 L})(L^{\beta_6 + \beta_7 K})R^{\beta_8}$.

[3] Data and complete statistics are available from J. H. te Kloot.

The Durbin-Watson (D-W) statistic for the CES capital side relation indicates the likely presence of positive autocorrelation. This case is thus chosen to illustrate the effect of corrective procedures. Analysts most commonly employ either the inclusion of a lagged dependent variable as an independent variable or a partial differencing procedure based on an estimate of a first-order autoregressive structure [8, 17, 18]. This comparison is also made for additional estimates of the CES based on the number of sheep shorn as the surrogate output variable. Although this variable is not as appealing an index of output as is wool, the example highlights the fact that autocorrelation depends on the specification of variables in the model and affords a convenient further comparison for this aspect of the hypothesis. These results are sketched in Table 2.

TABLE 2: *Rates of Technological Change via the CES Function With Alternative Adjustments for Autocorrelation*

| Output measure and method of estimation | Rate of technological change | $\bar{R}^2$ [a] | D-W(h) |
|---|---|---|---|
| Wool—Capital side relation— | | | |
| Untampered .. .. .. .. | −0.0167 | 0.17 | 1.04 |
| Lagged dependent variable .. .. | −0.0114 | 0.36 | 2.01 (0.09)[d] |
| Partial differences[b] .. .. .. | −0.0201 | 0.37 (0.10) | 1.93 |
| Sheep shorn[c]—Capital side relation— | | | |
| Untampered .. .. .. .. | −0.0232 | 0.38 | 0.85 |
| Lagged dependent variable .. .. | −0.0158 | 0.62 | 1.95 (0.26)[d] |
| Partial differences .. .. .. | −0.0282 | 0.64 (0.29) | 2.09 |
| Sheep shorn—Labour side relation— | | | |
| Untampered .. .. .. .. | −0.0173 | 0.56 | 1.57[e] |
| Lagged dependent variable .. .. | −0.0161 | 0.54 | 1.63 (2.65)[d] |
| Partial differences .. .. .. | −0.0171 | 0.56 (0.47) | 1.99 |

[a] Adjusted coefficients of multiple determination are comparable within each of the three groups. The coefficient in parenthesis for a partial difference equation is $\bar{R}^2$ as conventionally calculated but the other coefficient has been recalculated using the total sum of squares from the respective untampered equation.

[b] Partial differences of all regression variables were calculated using (1 − 0.5 (D-W)) as an estimate of the autocorrelation coefficient.

[c] Equations in which sheep shorn is the output variable all incorporate current year rainfall as an additional explanatory variable, it being significant in the regression equation.

[d] Durbin's (standard normal) large-sample test $h$ statistic for the case of a lagged dependent variable [5].

[e] This value falls in the indeterminate region of a 5 per cent significance test. The labour side relation for the wool-output CES tested null for autocorrelation (*see* Table 1), so adjustment was indicated only ambiguously.

Comparison is best made within each of the three groups of regressions since our intention here is to observe the effects of methods of handling autocorrelation. For the wool-capital side relation and the sheep shorn-capital side relation the partial difference equations suggest a greater negative rate of technological change than the respective untampered equations, whereas the equations including lagged dependent variables suggest less negative rates. Changes in implied rates of technological change are not so drastic for the sheep shorn-labour side relation but it should be noted that for this relation the untampered equation is apparently not very autocorrelated and the corrective measures do not perform as well as in the previous two relations.

## 5 DISCUSSION AND CONCLUSIONS

All the estimates indicate a negative rate of assumed neutral technological change which, if true, means that capital and labour now used yield less output than the same quantities would have in past years. In general, the results obtained were not of high statistical reliability as indicated by goodness-of-fit measures and by significance tests of estimates of the structural parameters. The poor statistical quality observed is probably caused by the considerable year-to-year fluctuations in productivity caused by environmental factors, and by the identification problems associated with the tendency for the firm to combine resources in similar ratios over time. These considerations, when coupled with what seems to be the reality of relatively small rates of technological change (of the order of $|0.01|$ a year), would lead one to anticipate poor statistical reliability of estimation of such rates.

Questions of statistical reliability aside, we can offer some tentative speculation about our observation of negative technological change. Ecologists have argued (in a different jargon) that productivity has fallen as a result of degradation of Australian rangelands through poor grazing management. Indeed, such ideology inspired Duncan [4] to his investigation in which he emphatically rejected the argument. Our results contribute marginally to a further questioning of his rejection, although we are unaware of any physical or ecological deterioration of the specific rangeland area that we studied.

However, our main thrust in this report is methodological. Our guess is that a similar degree of sensitivity to specification will be found in cases where data and statistics give one greater confidence in the results. Likewise, it probably matters little in terms of judging the importance of sensitivity whether technological change be determined as positive or negative.

The production functions we used all have some attributes which would favour their use and some which would cause one to want to shun them. As functions become less restrictive they do, unfortunately, become more complicated and so it becomes more difficult to interpret results derived from them. The assumptions inherent in linear side relations must at best be only partly realistic. On the other hand, however, resorting to simple production functions may impose too many restrictions on the paramaters for the functions to be descriptively valid.

Most published work on technological change concentrates on commentary of a few point estimates of rates of change—perhaps over a succession of epochs. The variance of such estimates is seldom reported—perhaps because in the popular CES function, this variance is a complex function of the variance of the estimated elasticity of substitution.

Our work emphasizes that there is another variance, over and above that inherent in any particular estimate; namely, "model and method variance". It is not too obvious to us what implications this has for students of technological change except possibly to engender an increased irreverence for particular point estimates that have appeared and probably will continue to appear in the literature. A circumspect, cautious approach to interpretation is this field of applied econometrics is suggested as being especially appropriate.

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