Adaptive Technology Strategies and Technical Efficiency: Evidence from the Sri Lankan Agricultural Machinery Industry

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Abstract

Recent research has highlighted the importance of technology strategies in influencing the economic performance of firms in developing countries. Attention has focused on two types of strategies; the first which involves adopting technologies developed elsewhere without undertaking any modifications and the second which involves investing in such technologies but adapting them to suit firm-specific needs and circumstances. Whilst it has been indicated that the second type of adaptive strategy is likely to lead to higher productivity gains than the first, this hypothesis has not been tested econometrically. Using survey data, this paper undertakes an econometric analysis of the effects of these alternative technology strategies on firm-level technical efficiency in the agricultural machinery industry in Sri Lanka. Controlling for other possible determinants, it finds that adaptive strategies have a significant positive effect on efficiency in this industry.

Keywords: Industry, Technology, Efficiency

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Introduction

Recent studies have highlighted the role of technology development in promoting industrialisation in developing countries (Pack 1992; Lucas 1993). Although firms in developing countries do not innovate at the global technology frontier, or even undertaken formal research and development (R&D), they have been shown to be actively engaged in more informal and adaptive types of technical change (Evenson and Westphal 1995). Research has indicated that the type of technology strategy adopted by developing country firms can have a significant impact on their economic performance (Bell and Pavitt 1993; Hobday 1995; Lall and Teubal 1998).

Although developing country firms are generally dependent on technologies developed elsewhere, the manner in which they use and manage this technology can vary considerably (Katrak 1990; Rodrik 1995; Lee 1996).[1] In particular, empirical studies have drawn attention to two types of technology strategies. The first involves the purchase and use of existing technologies (such as capital goods) with very little in-house adaptation and requires relatively little in-house effort on the part of the firm. The second strategy involves adopting existing technologies but undertaking continuous and cumulative adaptations to them. Such a strategy requires considerable in-house effort and expertise[2].

A central hypothesis advanced by the recent literature is that the second type of technology strategy is likely to lead to higher productivity gains than the first (Malerba 1992; Lall 1996). The is attributed to the fact that technologies are not characterised by pre-determined levels of efficiency and that the level of operating efficiency obtained from a given technology is determined by firm-specific efforts to assimilate and modify it suit particular circumstances. While such efforts in industrialised and newly industrialised countries usually involves undertaking formal R&D, adaptive technical change in low income developing countries is typically informal and low cost.

The empirical literature on technology strategy in developing countries is still at a relatively early stage, however, and the effects of alternative strategies on the economic performance of firms has not been investigated in a rigorous and satisfactory manner. Whilst a few studies have examined the economic effects of adaptive R&D undertaken in newly industrialised countries (Aw and Batra 1998), econometric analysis of the effects of informal adaptive technology strategies on productive efficiency is much more limited. Much of the existing empirical research on the issue is limited to qualitative case studies of individual firms and these findings have not been verified for larger samples of firms in a reliable and generalisable way.

To address this gap in the literature, this paper undertakes an econometric analysis of the effects of alternative technology strategies on firm-level technical efficiency in the agricultural machinery and equipment sector in Sri Lanka. Using cross-section survey data, we test the hypothesis that firms which adapt and alter technologies achieve greater levels of technical efficiency than those who adopt existing technologies but undertake no subsequent modifications. While there is a substantial body of econometric research on the determinants of firm-level technical efficiency in developing countries (see for example, Chen and Tang 1987), these studies have not examined the effects of technology strategies on efficiency determination. This paper, therefore, will also serve to address this gap in the efficiency literature.

The agricultural machinery and equipment industry in Sri Lanka is suitable for this analysis for two reasons. Firstly, firms in this industry use imported production technology (usually general purpose machinery) which has scope for firm-level adaptation. Secondly, it is a low technology industry and an analysis of the economic effects of adaptive technology strategies in such an industry will provide a useful counterpoint to previous qualitative studies which have focused on high technology industries such as steel and precision engineering.

The paper is organised as follows. Section 1 deals describes the data and outlines some theoretical issues relating to technology strategies and efficiency. Section 2 derives the dependent variable, technical efficiency, and also describes the independent variables to be used. Section 3 presents the results of the econometric analysis of the effects of technology strategies on technical efficiency and Section 4 provides the conclusions.

1.1 The Data

Data to analyse the economic effects of informal technology strategies in developing countries is not easily available in published large-scale surveys. For this reason, the analysis in this paper is based on data from a field survey of 35 Sri Lankan firms in the agricultural machinery and equipment industry. This dataset contains firm-level information on informal technology strategies. It also contains the production and financial information required to estimate technical efficiency and is therefore especially suitable for our analysis.

The survey gathered information on the types of technological activities undertaken by firms over a 5 year period (1987-1992). The focus of the survey was on process-related technological activity which mainly involved the adoption of new capital goods (mainly general purpose machinery) and their subsequent adaptation. All firms in the sample had purchased at least one new piece of capital equipment (such as a lathe, boring machine or drilling machine) during the five year period under consideration . However, only some of them subsequently adapted and modified these technologies in any way. Therefore, the sample consists of two groups; one which invested in new technology but undertook no subsequent adaptations and another which invested in new technology and adapted it to suit their specific needs. This makes the sample suitable for analysing the relative economic merits of the two types of technology strategies described above. The adaptive efforts displayed by firms included improving the quality and performance of inputs, altering technologies to cope with new materials and inputs, bottleneck breaking, improving by-product utilisation and capacity stretching. All of these efforts were informal ones and did not involve formal R&D.

The fact that all firms in the sample had undertaken some technology investments in the period under consideration deserves comment. This was not due to the sample being deliberately restricted to such firms. The firms were picked randomly, using a census list of all manufacturing firms. Two explanations of why all firms had invested in new technology can be given : the simple (and therefore low cost) nature of the technological investments in question and the fact that these investments were observed over a fairly long period (i.e 5 years). Consultation with industry sources confirmed that most firms in the industry are likely to have purchased at least one simple capital good in a given 5 year period.

In order to make comparisons between alternative technology strategies meaningful, the sample was restricted to firms using similar technologies and manufacturing similar products. Most firms in the sample manufactured simple products such as small hand tools, pumps, power tillers, sprayers, threshers and shellers and producers of large, mechanised products such as tractors were excluded from the sample. All firms also undertook basic cutting, bending, forging and welding operations using general purpose tools and simple, powered equipment.

However, given that firms in the sample did not manufacture a homogenous product, it is important to consider whether technology adaptation was a function of the type of product manufactured (i.e whether the production of certain types of agricultural machinery did not require the adaptation of imported technology). If this were the case, investigating the effects of technology adaptation on efficiency would not be an useful exercise. Close scrutiny of the data, however, revealed no relationship between the extent of adaptation undertaken and product type.

1.2 The Relationship Between Technology Strategy and Productive Efficiency: Theoretical Considerations

As noted above, we focus on two types of technological strategies;

Strategy 1: investing in new technologies developed elsewhere.

Strategy 2: investing in new technologies and subsequently adapting and modifying them.

The relationship between these two strategies and productive efficiency can be analysed in several ways.

According to the simple neoclassical model the frictionless functioning of the market permits the use of best practice technology at every point in time on the basis of current investments. The efficient functioning of the firm in this scenario only requires that we 'get the prices right'. This model assumes that 'best-practice' technologies are well-defined and that they can be easily picked from a shelf of blueprints. Firms which pick a blueprint automatically achieve best-practice levels of efficiency. The model leaves little scope for incremental adaptation of technologies and firm-level learning to influence efficiency. According to this model, therefore, firm which adopt Strategy 1 should easily achieve maximum levels of efficiency and there are no clear theoretical grounds for predicting differences in technical efficiency between firms adopting Strategy 1 and Strategy 2.

This view is challenged by more recent evolutionary models which postulate a strong positive link between adaptive technology strategies and efficiency at the firm-level (Nelson and Pack 1996). In particular, the evolutionary approach has drawn attention to the fact that firms using similar technologies can achieve markedly varying levels of productivity because any technology is always used in a firm-specific manner. This is largely because technology is characterised by tacitness which means that no technique is completely expressed by codified information and material inputs (Metcalfe 1993). Technologies, therefore, need to be operationalised and assimilated into firm-specific contexts and this involves adaptive technical change. This approach therefore predicts that firms using Strategy 2 will achieve higher levels of efficiency than those adopting Strategy 1.

Evolutionary models also posit that there is potential for adaptive technology strategies (Strategy 2) in most types of manufacturing activities (Nelson and Pack 1999). Thus, the need to assimilate and adapt technologies to firm-specific contexts is seen as generic to manufacturing activity. While it is conceivable that in technologically complex industries, manufacturing technologies have to be specifically developed and assimilated according to the requirements of the end-product, it is argued that adaptation is prevalent even in low technology industries where simple machinery is purchased off-the shelf. This is because

> only a small portion of what one needs to know to employ a technology is codified in machine manuals, blueprints and textbooks. Enhancing efficiency, therefore, involves a process of trial-and error manipulation and adaptation at the firm level.

The predictions of the evolutionary approach receives support from empirical research on technology accumulation in developing countries. Qualitative case studies have shown that purchasing a new technology with efficiency enhancing potential is only the first step in achieving higher levels of productive efficiency. They have highlighted importance of in-house efforts to assimilate and alter this technology to suit firm-specific circumstances (Dahlman and Fonseca 1987; Katz 1987). These studies have indicated that minor adaptive efforts can produce potentially large efficiency gains. In order to verify these findings further, however, it is important that we subject them to more rigorous econometric testing using cross-section samples of firms.

2. Estimating the Economic Effects of Technology Strategies: Deriving the Variables

2.1 The Dependent Variable: Technical Efficiency

The econometric analysis in this paper examines the effects of two alternative technology strategies on firm-level technical efficiency. The microeconomic concept of efficiency is based on the concept of a frontier production function which defines the outer boundary (or best practice) of all input-output combinations. Deviations from best-practice are ascribed to technical inefficiency.

We estimate the dependent variable, technical efficiency, using the widely used stochastic frontier model developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). The function postulates the existence of technical inefficiency in production of firms employing similar level of technology and producing similar outputs. Estimation of the stochastic frontier production function assumes a function relating the maximum possible output to certain inputs, such that, for a given firm *i*.

$$y_i = f(x_{i,} b) + \varepsilon_i \qquad (1)$$

where $i = 1....n$; y_i is output for observation *i*, x_i is a vector of inputs for observation $i;b$ is a vector of parameters and ε_i is the error term for observation *i*.

The stochastic model postulates that the error term is made up of two independent components

$$\varepsilon_i = v_i - u_i \qquad (2)$$

where v_i ~N(0, σ^2_v) is a two sided error term representing the statistical noise found in any regression equation and $u_i.\geq 0$ is the one sided error component representing technical inefficiency. This paper assumes that the distribution of u_i is derived from a N(0, σ^2_u) distribution truncated above at 0.

Having estimated the model, we can obtain the residuals given by

$$\varepsilon_i = y_i - f(x_i, \beta) \qquad (3)$$

which can be regarded as estimates of the error term, ε_I.

As shown by Jondrow et al (1982) ε only contains imperfect information about *u* and makes it possible to estimate mean technical efficiency over all observations. Jondrow et al (1982) also show that firm-specific technical efficiency can be inferred from asymmetry in the residuals around a fitted production function and its calculation rests on the higher moments of these residuals. They show that a firm specific measure of technical inefficiency, that is a point estimate of u_i, can be obtained by calculating the mean of the conditional distribution of u_i given ε_I.

They define the following

$\sigma^2 = \sigma^2_v + \sigma^2_u$, $u_* = -\sigma^2_u\varepsilon/\sigma^2$, $\sigma_*^2 = \sigma^2_u\sigma^2_v/\sigma^2$.

The conditional distribution of u given ε is then that of a N~ (μ_*, σ_*^2), variable truncated at 0. This distribution can be used to make inferences about *u*.The mean of the conditional distribution of *u* given ε is shown by

$$E(u|\varepsilon) = \mu_* + \sigma_* \left[\underline{f(-\mu_*/\sigma_*)} / 1-F(-\mu_*/\sigma_*)\right] \qquad (4)$$

where *f* and F represent the standard normal density and cumulative density functions, respectively and $-\mu_*/\sigma_* = \varepsilon\lambda\sigma$ where $\lambda = \sigma_u/\sigma_v$. Equation 4 can thus be rewritten as

$$E(u|\varepsilon) = \sigma_* \{[f(\varepsilon\lambda/\sigma) / 1-F(\varepsilon\lambda/\sigma)] - (\varepsilon 8/\sigma)\} \qquad (5)$$

In Equations 4 and 5, μ_* and σ_* are unknown and are estimated by μ_* and $\sigma_* > \sigma_*$ respectively. Equation 5 yields the point estimate of u_i which is then used to obtain firm-specific technical efficiency (TE_i) as given by

$$TE_i = \exp(-\mu_I). \qquad (6)$$

The above model is used to estimate firm-specific technical efficiency and the results of the estimation are shown in Table 1. Technical efficiency is estimated for a single year, 1992. The Cobb-Douglas production function was adopted as the functional form. While other forms such as the translog function are more flexible, it consumes more degrees of freedom and reduces the precision with which parameters of the production function can be estimated[3]. The dependent variable is the natural logarithm of value added. LnK and lnL are the natural logarithms of the capital and labour measures respectively. Capital is measured in terms of historic costs.[4] The capital stock measure was turned into a flow of capital services using the annuity formula assuming a discount rate of 10% Labour was measured in terms of 'unskilled equivalent person days' which combines skilled and unskilled labour. The ratio of skilled to unskilled wages was used for the conversion. VINT is capital vintage variable and is defined as the average age of machinery used by a firm. This variable is commonly used as a control variable when estimating frontier production functions.

The method of estimation was maximum likelihood, using the David-Fletcher-Powell algorithm. Starting values for the maximum likelihood estimates were obtained from an initial OLS regression. OLS estimates are also used to obtain starting values for the variance parameters of the model. With the exception of the constant term, OLS estimates are consistent, albeit inefficient. The parameter estimates for labour and capital have the expected signs and significance levels.[5] Firm-specific indices of technical efficiency are obtained using Equation 6.

Table 1: Stochastic Frontier Estimates

Independent Variable	
LnL	.78 (.20)***
LnK	.49 (.16) ***
VINT	.28 (.21)
Constant	.75 (.87)
Log Likelihood	-27.59

Standard errors in parantheses
*** denotes significance at the 1 per cent level.

2.2 The Independent Variables

Technology Strategy: The central hypothesis to be tested is that firms which invest in new technologies and adapt them to their specific requirements (undertake Strategy 2) achieve higher levels of technical efficiency than those who adopt new technologies but do not undertake subsequent modifications (undertake Strategy 1). We test this hypothesis using a single dummy variable TECSTRAT which takes the value 1 if Strategy 2 was adopted and 0 if Strategy 1 was adopted.

In order to isolate the effects of technology strategy on technical efficiency, it is important that the following independent variables conventionally used when estimating the determinants of technical efficiency are also included.

The Age of the Firm: A positive relationship between the age of the firm and technical efficiency can be expected due to learning-by-doing effects. Learning-by-doing would occur automatically as a result of experience accumulation and would lead to a fall in production costs over time. In contrast to Strategy 1 and Strategy 2 which both involve purposive investments in technology, learning-by-doing is essentially a costless process which occurs as a function of time. The variable AGE, the age of the firm, is used to capture learning-by-doing effects.

Firm Size: Scale economies can give rise to a positive link between firm size and efficiency. A negative link could also occur if large firms experience diseconomies in production due to problems of management and supervision. The existing evidence from developing countries does not suggest a strong link between efficiency and firm size in either direction (Little, Mazumdar and Page 1987; Cortes, Berry and Ishaq 1987). We include the independent variable SIZE which is the total number of employees in a firm. To minimise problems of causality (given that the relationship between efficiency and size could take the reverse direction), we take the average number of employees for the five years prior to the year in which efficiency is estimated.

Foreign Equity: Firms with foreign equity may have higher levels of efficiency than domestic ones if they have greater access to proprietary technological knowledge and superior management practices. To capture the effects of foreign equity we use the variable FOREIGN which is the percentage of foreign equity in a firm .

Capacity Utilisation: We also include a variable, CU, which is the capacity utilisation rate in 1992. This variable is conventionally included as a control variable when estimating the sources of firm-level technical efficiency.

Technological Skills and Capabilities: Recent research has indicted that technological skills and capabilities can have a positive effect on firm-level productive efficiency (Lall and Teubal 1998). Special emphasis has been placed on the role of industry-specific skills and knowledge in boosting firm performance. We include two variables which capture industry-specific technological capabilities. TECHED measures the proportion of a firm's workforce who are graduate engineers. TECHMAN refers specifically to the capabilities of the decision makers in the firm and is a dummy variable relating to whether any senior managers were graduate level engineers.

3. The Effect of Technology Strategies on Technical Efficiency: The Results

A single equation model is estimated using OLS regression. The dependent variable is TE, the firm -specific measure of technical efficiency derived in Section 2.1 and the independent variables are those listed in Section 2.2. The results of the estimation are given in Table 2. Several diagnostic tests were carried out to check the reliability of the estimations. The modified

Glesjer test confirmed the assumption of homoskedasticity. The RESET test and tests for normality of errors indicated that the assumptions of linearity and normality were maintained (Table 2).

Table 2: The Effect of Technology Strategies on Efficiency

Independent Variables	Equation 1	Equation 2
TECSTRAT	.06 (2.3)**	
TECHIND		.12 (2.8)**
SIZE	-.009 (-.381)	-.03 (-.7)
AGE	.008 (.35)	.011 (1.5)
FOREIGN	.08 (1.3)	.06 (1.06|)
TECHED	.09 (2.2) **	.13 (3.1) **
TECHMAN	.02 (2.3)**	.06 (2.2)
CU	.001 (1.89) *	.006 (0.8)
Constant	.60 (4.0)**	.54 (4.4)**
R^2	.41	.39
F	3.2 **	3.4 **
RESET test	F= o.25 (3,17)	
N	35	35

t-values in paranatheses, except for RESET test, where degrees of freedom are in parantheses.
* denotes significance at 10 per cent level.
** denotes significance at 5 per cent level.

The central hypothesis relating to technology strategy is upheld in the estimation. The variable TECSTRAT is positive and significant at the 5 per cent level indicating that firms which invest in new technologies and modify them to suit their specific requirements achieve higher levels of efficiency than those who introduce new technology but do not carry out subsequent adaptations. Whilst the importance of adaptive technical change has been emphasised by previous research, this specific hypothesis has not been subject to econometric testing in the context of firms in low income LDCs.

Several reasons can be given to explain the positive effect of adaptive technology strategies on firm-level efficiency. Firstly, given that the industry is a low technology one, relatively low levels of in-house skills are required to identify appropriate types of adaptive change and the risk of making wrong choices (which could lower technical efficiency) is small. Secondly, such changes can be assimilated without many disruptions to a firm's manufacturing process. This means that efficiency gains from these efforts can be realised within a short period of time and are likely to show up in our single period measure of technical efficiency. Thirdly, continuous minor changes have been shown to have a cumulative effect on productive efficiency (Katz 1987). Even though our study only relates to technological activities undertaken over a five year period it is likely to have captured such cumulative effects.

Up to now, much of the research on the economic effects of adaptive technology strategies has focused on high technology industries in newly industrialised countries (Aw and Batra 1998). Our analysis shows that even the simple, low cost adaptive efforts typically undertaken by developing country firms in technologically simple industries pay off in terms of productive efficiency. It indicates that firms using very similar technologies can achieve very different levels of efficiency depending on the technological strategy followed after the initial adoption of the technology. Thus, improving productive efficiency even in a low technology industry such as agricultural equipment manufacture is not an easy process which only involves the purchase of new general purpose capital equipment. The agricultural machinery industry is essentially a 'first level' capital goods industry in most low income developing countries and high levels of firm-level productive efficiency are important for the growth and dynamism of the industry. We have been able to identify one important source of such dynamism.

By showing that technology strategy is an important determinant of firm-level technical efficiency in this industry, our analysis has also drawn attention to a factor which has largely been overlooked by the literature on efficiency determination in developing countries. Existing studies on the sources of efficiency generally only capture technology effects by including a variable relating to the vintage of capital equipment. Such variables do not capture the type the dynamic aspects of adaptive technological strategies. Empirical research on the determinants of technical efficiency in industrialised countries has shown that technological effort involving formal R&D generally has a strong positive influence on firm-level efficiency (Caves and Barton 1990; Hanusch and Hierl 1992). Our analysis has demonstrated that informal, adaptive technological efforts can influence efficiency among developing country firms.

One shortcoming of using a single technology strategy dummy variable such as TECSTRAT is that it fails to capture the extent of adaptive change undertaken by each firm. To overcome this problem we carried out an alternative estimation using a continuous technology strategy variable. This was a composite index which summarised the various types of adaptive change undertaken by each firm. The survey indicated that five types of adaptive change (improving components, capacity stretching, bottleneck breaking, substituting inputs and altering capital equipment to cope with new inputs) were common among firms in the sample and the index was computed by awarding each firm with a single point for each of these changes undertaken. The total points for each firm were then aggregated and averaged to create a firm-specific index of adaptive change.[6] An alternative estimation was then undertaken using this index (TECHIND) instead of the technology strategy dummy variable (Equation 2 in Table 2). This variable, too, was significant and positive in the estimation, indicating that the extent of adaptive change undertaken is positively related to efficiency: i.e the more adaptive change a firm undertook, the more efficient it was.

The two variables relating to technological capabilities, TECHED and TECHMAN, were also significant and positive in the estimation indicating that the type of specialised technical education and training they capture generates industry-specific capabilities which lead to higher levels of operating efficiency. This accords with previous research on the effects of industry-specific capabilities on firm-level economic performance (Deraniyagala and Semboja 1999). We examined whether there were any interaction effects between these two capability variables and TECSTRAT, but the interaction terms were not significant.[7]

The variable relating to foreign equity and firm size , FOREIGN and SIZE, were not significant in the estimation. This accords with previous research which does not point to a particularly strong relationship between these factors and efficiency (Little, Page and Mazumdar 1987; Cortes 1987). The capacity utilisation variable CU is only significant at the 10 per cent level.

The variable AGE is not significant in the estimation indicating that learning-by-doing, which occurs merely as a function of time, does not have an independent effect on technical efficiency. This could be due to inefficient production methods and routines becoming established in firms over time. Together with the significance of the technology strategy variable, this indicates that costless and automatic experience accumulation is not as important as dynamic, costly technology adaptation in determining firm-level efficiency.

Whilst our analysis has shown that the adaptation of manufacturing technologies has a positive effect on productive efficiency, it is also important to consider the broader generalisability of this result. An important question which arises is whether the need to adapt manufacturing technology depends on the end-product being produced. In other words, are there a large number of products which can be manufactured by developing country firms by directly using imported technology, thus rendering our results only relevant to the agricultural machinery sector in Sri Lanka? Both theoretical and empirical work indicate that the answer to this is negative.

At the theoretical level, as noted in Section 1.2, models of firm behaviour have emphasised that all or most technologies need to be adapted and assimilated at the firm-level to suit specific circumstances (Malerba 1992; Nelson and Pack 1999). In these theories, circumstantial specificity is a fundamental and generic characteristic of technology, and technology adaptation becomes central to improving productive efficiency.

At the empirical level, empirical studies shown manufacturing technology adaptation to be widespread in a range of product groups. Case studies of individual firms in industries such as steel, cement and automobiles have shown technologically dynamic firms to undertake extensive technology adaptation (Dahlman and Fonseca 1987; Maxwell 1987; Lall 1987). Also revealing are case studies which focus on East Asian firms in a range of industries and document the slow and painstaking process of manufacturing technology adaptation which resulted in dramatic improvements in efficiency and international competitiveness (Kim 1997; Hobday 1995; Goto and Odagiri 1997). Whilst many of these studies dealt with heavy and high technology industries the present study show technology adaptation to be widespread in a relatively low technology sector. Overall, therefore, the existing empirical evidence indicates that manufacturing technology adaptation is not a function of the end product manufactured. Our results relating to the positive effects of technology adaptation on efficiency, therefore, appears to be broadly generalisable. It is important, however, to consolidate this point further through future research on the effects of adaptation on productive efficiency in other low technology industries.

Some limitations of the empirical analysis in this paper must also be noted. Firstly, due to data limitations our analysis was constrained by the use of a single period measure of efficiency. While adaptive technology strategies emerged as a significant determinant of single period efficiency, it is also important to examine their effects on longer term productivity growth. This should issue should be taken up by future research. Secondly, the issue of whether technology strategies affect efficiency jointly with other independent variables should be investigated further. In particular, the question of whether firms who are both technologically dynamic and have high levels of human capital and technological capabilities are more efficient than those which display only one characteristic deserves further analysis. Whilst our preliminary estimations indicated that such joint effects were not important, it is important for future research to investigate these issues further using larger samples of heterogeneous firms.

4. Conclusion

Recent research has emphasised that technology accumulation can have a strong influence on the economic performance of firms in developing countries. In particular, attention has been drawn to two types of technology strategies common among developing country firms. Strategy 1 involves investing in new technology but not undertaking subsequent modifications to it, whilst Strategy 2 involves investing in new technology and also adapting it to suit firm-specific circumstances. It has been hypothesised that Strategy 2 is likely to lead to higher firm-level efficiency than Strategy 1. Up to now, however, this hypothesis has not been subject to econometric testing using samples of firms from low income developing countries and empirical research on the issue has consisted mainly of qualitative case studies.

This paper sought to verify this hypothesis by undertaking an econometric analysis of the impact of technology strategy on firm-level technical efficiency in the agricultural machinery sector in Sri

Lanka. The results showed firms adopting Strategy 2 to have higher levels of efficiency than those adopting Strategy 1. Our study , therefore, provides strong support for the argument that productivity enhancement in developing country firms is not merely a straightforward process of purchasing new technologies and that considerable in-house effort to operationalise these technologies is required.

This study enhances existing research in several ways. Firstly, by undertaking an econometric exercise we were able to complement the findings of previous qualitative studies on the issue. Given that the methodology used here enables us to reach more reliable and generalisable conclusions than the earlier case studies, our findings strengthen arguments relating to the importance of firm-level technological dynamism in developing countries.

Secondly, we were able to isolate the effects of technology strategies on efficiency by controlling for other potential determinants. In so doing, we also added a new dimension to the literature on efficiency determination in developing countries which has up to now largely overlooked the issue of technology and focused on the effects of factors such as firm size, export-orientation and foreign ownership. By including these variables together with technology variables, our estimations have indicated that previous studies may have overlooked an important determinant of technical efficiency.

Finally, by analysing the effects of technology strategies on the economic performance of firms in a low technology industry this study provides a useful counterpoint to previous research which has focused mainly on high technology sectors. The agricultural machinery sector is usually a 'first-rung' industry in the path of industrialisation in most developing countries. Understanding the relationship between firm-level technological behaviour and productive efficiency this industry, therefore, has important wider implications.

References

Aigner, D. C. Lovell and P Schmidt (1977) ' Formulation and estimation of Stochastic Frontier Production Function Models', *Journal of Econometrics*, **6**, 31-37.

Aw, B and G. Batra (1998) 'Technological Capability and Firm Efficiency in Taiwan', *World Bank Economic Review*, **12** , 59-79.

Bell, M and K. Pavit (1993) 'Accumulating Technological Capability in Developing Countries' *Proceedings of the World Bank Annual Conference on Development Economics* 1992.

Caves, R and D. Barton (1990). *Technical Efficiency in US Manufacturing Industries*. Cambridge:MIT Press.

Chen, J and D. Tang (1987) 'Comparing Technical efficiency Between Import- Substituting and Export Oriented Firms in a Developing Country', *Journal of Development Economics*, **26,** 277-89.

Cortes, M, A. Berry and A. Ishaq (1987). *Success in Small and Medium Scale Enterprises:Evidence from Colombia*. Oxford:OUP.

Dahlman, C. and F. Fonseca (1987) ' From Technological Dependence to Technological Development; the case of the USIMINAS steel plant on Brazil' in J. Katz (ed) in J. Katz (ed) *Technology Generation in Latin American Manufacturing Industries*. Basingstoke: Macmillan.

Deraniyagala, S and H. Semboja (1999). ' Trade Liberalisation, Firm Performance and Technology Upgrading in Tanzania' in S. Lall (ed) *The Technological Response to Import Liberalisation in Sub-Saharan Africa*. Basingstoke:Macmillan.

Evenson, R and L. Westphal (1995) ' Technological Change and Technology Strategy.' in J. Behrman and T.Srinivasan (ed) *Handbook of Development Economics* Vol 3A (North -Holland).

Goto, A and O. Hiroyuki (1997), *Innovation in Japan*. New York: Oxford University Press.

Hanusch, H. and Hierl, M (1992) 'Productivity, Profitability and Innovative behaviour in West German Industries' in F. Scherer and M. Perlman(ed) *Entrepreneurship, Innovation and Economic Growth.* Ann Arbour: University of Michgan Press.

Hobday, M (1995) *' Innovation in East Asia ; the Challenge to Japan'* . Cheltenham, UK: Edward Elgar Publishing Co.

Jondrow, J,. K. Lovell. I. Materov and P. Schmidt (1982) ' On the estimtation of Technical Inefficiency in the Stochastic Frontier production Model', *Journal of Econometrics* **19,** 233-238.

Katrak, H (1990) ' Imports of Technology and the Technological efforts of Indian Enterprises' , *World Development*. **18**, 371-381.

Katz, J (1987) 'Domestic Technology Generation in LDCs: a Review of Research Findings' in J. Katz (ed) *Technology Generation in Latin American Manufacturing Industries*. Basingstoke: Macmillan.

Kim, (1997) From Imitation to Innovation: Dynamics of Korea's Technological Learning Process. Boston: Harvard Business School Press.

Lall, S (1996) 'Paradigms of Development: the East Asian Debate', *Oxford Development Studies*, **24**, 111-131.

Lall, S (1987) *Learning to Industrialise.* Basingstoke and London: Macmillan.

Lall, S. and M. Teubal (1998) ' Market Stimulating Technology Policies in Developing Countries: A Framework with Examples from East Asia', *World Development,* **26**, 1369-1385.

Lee. J (1996) ' Technology Imports and R&D Efforts of Korean Manufacturing Firms', *Journal of Development Economics,*. **50**, 197-210.

Little, I. D. Mazumdar and J. Page (1987) *Small Manufacturing Entreprises: A comparative Analysis of India and Other Economies.* Oxford:OUP.

Lucas, R. 1993. 'Making of a Miracle', *Econometrica*, **6**, 251-72.

Malerba, F (1992) 'Learning by Firms and Incremental Technical Change', *Economic Journal*, **104**, 845-859.

Meeussen, W and J. van den Broeck (1977) 'Efficiency Estimations from Cobb-Douglas Production Functions with Composed Error Terms', *International Economic Review*, **18**, 435-44.

Maxwell, P (1987) 'Adequate Technology Strategy in an Imperfect Economic Context: the Case of the Acindar Steelplant in Argentina' in J. Katz (ed) *Technology Generation in Latin American Manufacturing Industries*. Basingstoke and London:Macmillan.

Metcalfe, S (1993) ' The Economic Foundataions of Technology Policy: Equilibrium and Evolutionary Perspectives'. Department of Economics, University of Manchester, Manchester.

Nelson, R and H. Pack (1999) 'The Asian Miracle and Modern Growth Theory'. *Economic Journal*, **109**, 416-436.

Nelson, R and H. Pack (1996) ' Firm Competencies, Technological Catch-Up and the Asian Miracle'. Paper presented to the Sixth Conference of the International Joseph Schumpeter Society, Columbia University and University of Pennsylvania. Stockholm.

Nelson , R (1981) 'Research on Productivity Growth and Productivity Differences: Dead Ends and New Departures', *Journal of Economic Literature*, **19** , 1029-64.xxxv.

Pack, H. (1992) ' Learning and Productivity Change in Developing Countries' in G. Helleiner (ed) *Trade Policy, Industrialisation and Development* Oxford: Clarendon pp 21-45.

Rodrik, D. (1995) ' Trade and Industrial Policy Reform. in J. Behrman and T. Srinivasan (ed) *Handbook of Development Economics* Vol 3B (North -Holland).

Notes

[1] This refers mainly to low income developing countries who do not typically create and develop new innovations.

[2] These two strategies are mainly relevant to low income developing countries which are far below the global technology frontier. Some firms in industrialised countries would also tend to create and develop their own technologies.

[3] Trial estimations of the translog function showed them to suffer from problems relating to degrees of freedom.

[4] The dataset contained information on the acquisition costs of capital and on the dates of acquisition. These were deflated using 1982 prices and aggregated. The capital stock measure was turned into a flow of capital services using an annuity formula and assuming a discount rate of 10 per cent (see Little, Mazumdar and Page 1987 for a similar historic cost measure of capital.

[5] The fact that the vintage variable is not significant probably reflects the fact that all firms in the sample use broadly similar technologies.

[6] Firms which did not undertake any change all scored 0 on this index.

[7] This could be due to the small sample size which meant that adding more explanatory variables reduced the degrees of freedom in the estimation.