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Measuring the Rate of Technological Change in Chinese Rubber Smallholdings - A Micro-economic Approach

T.A. CHEW
University of Agriculture, Serdang, Selangor

Technological progress is commonly measured via *aggregate production functions. In this paper, technological progress is estimated from a micro-economic viewpoint. A Cobb-Douglas production function was fitted to t\ sets of cross-sectional data collected at different points in time. From the estimates obtain , we derived that the rate of technological progress in rubber smallholdings is the capita ıgmenting type at about 1.2% per year.*

Basically, technological progress consists of some change in the form of a production function which, besides expressing the relationship between the maximum amount of output and the inputs required to produce it, also describes the manner in which inputs are combined in varying proportions to produce a given output. Following Brown[1], technological change can be defined in terms of changes in the four characteristics of the abstract technology which a given production function embodies:

- Changes in the efficiency of a technology where the output is augmented for a given set of inputs, but where the relationship between the inputs and the degree of returns to scale are not altered
- Changes in the returns to scale brought about by modifications in the technology
- Changes in the ratios of the elasticities of production with respect to different factors which alter the marginal rate of substitution between different factors
- Changes in the elasticity of substitution between different factors.

This paper reports a piece of research in which estimates were made of the rate of technological change in Chinese rubber smallholdings in Peninsular Malaysia, in terms of the four characteristics outlined. A critical review of existing empirical work in this area is also given.

TECHNOLOGICAL PROGRESS IN THE RUBBER INDUSTRY: LITERATURE REVIEW

The rubber industry in Malaysia has experienced great technological progress. Much of this progress comes from systematic breeding work. An attempt to measure the rate of technological change in the Malaysian rubber industry was made by Yusoff[2] who assumed the following aggregate production function:

COMMUNICATION 751

$$q = f(K, A, L) \quad \ldots 1$$

where K is the total number of rubber trees representing capital

A is the total acreage of land planted with rubber

L is labour (tapping) in man-hours

q is the total product.

Assuming that the function is homogeneous of degree one and dividing *Equation 1* by A, we get:

$$\frac{q}{A} = f\left(\frac{K}{A}, \frac{L}{A}\right) \quad \ldots 2$$

Introducing technological progress in capital, we have:

$$\frac{q^*}{A} = f\left(\frac{\alpha(t)K}{A}, \frac{L}{A}\right) \quad \ldots 3$$

where $q^* \geqslant q$

$\alpha(t) \geqslant 1$

t represents time.

Assuming that the number of trees per acre and the number of man-hours per $\left(\frac{L}{A}\right)$ are used in fixed proportions maintained over time, *Equation 3* can be reduced to:

$$\frac{q^*}{A} = f'\left[\alpha(t)\right] \quad \ldots 4$$

Assuming that the yield per acre is growing exponentially over time as:

$$\left(\frac{q^*}{A}\right)_t = B_0 e^{\alpha(t)} k_t \quad \ldots 5$$

where $\left(\frac{q^*}{A}\right)_t$ is average yield per acre

B_0 is a constant
e is the base of natural logarithms
k_t is the error term

we obtain after converting to log form

$$\ln \frac{q^*}{A}_t = \ln B_0 + \alpha(t) + \ln k_t \quad \ldots 6$$

Using observations on the annual yield per acre from the estate sector, Yusoff[2] obtained a value of $\alpha = 0.0427$ and a R^2 of 97% in his estimate for *Equation 6* above. This implies that yield per acre is growing at a constant rate of 4.3% per year *i.e.* technological progress (capital-augmenting type) is 4.3% per year.

One criticism which is levelled against aggregate production function studies of technological progress is that the number of factors considered in the aggregate production function is necessarily limited. Hence, yield increases due to variable inputs, such as improved crop maintenance and increased fertiliser applications, may be erroneously attributed to improvements in capital stock, a fixed input.

Further, in Yusoff's[2] analysis, the assumptions of a constant number of trees per acre and constant number of tapping labour (man-hours) per acre are debatable. To investigate the changes in relationships between various factor inputs, between output and these factors and, lastly, the effects of these changes in terms of technological progress, micro-level production function analysis is perhaps more suitable analytically than macro-economic-type studies. There have been many successful attempts in recent years to measure technological change in a micro-economic context using production functions[3].

In a micro-level study of technological progress in the estate sector, Yee[4] identified four different technological strata and estimated the rate of technological improvements between the strata. Yee[4] used a Cobb-Douglas production function thus:

$$Y_j = \alpha_0 + \alpha_1 \ln N_j + \alpha_2 \ln T_j + \alpha_3 \ln F_j + \alpha_4 \ln E_j + \alpha_5 \ln MP_j + U_j \quad \ldots 7$$

where Y_j is the annual rubber output of field j measured in thousand kilogrammes

N_j is the harvesting labour measured in total number of tappings in field j

T_j is the total index value for the tappable trees in field j (corrected for the age factor)

F_j is the total kilogrammes of fertilisers applied in year t in field j

E_j is the other input expenditure measured in Malaysian ringgit

MP_j is the management proxy in terms of the gross profit to total expenditure ratio

U_j is the random error term

α_j are the parameters of the function.

The rates of technological progress between the different strata were estimated in terms of changes in the intercept and slope parameters. The rates obtained are shown in *Table 1.*

Unfortunately the estimating procedure used by Yee[4] is open to questioning. The total index value, T_j for the tappable trees, was estimated from yield curves constructed from sample data that was subsequently used for estimating *Equation 7.* It is therefore not surprising that the only change detected was a change in the intercept term (α_0 in *Equation 7*) - a Hick's neutral technological change. Any possible change in α_2 would not be detectable because T_j was estimated from Y_j itself. Nevertheless, the yearly rates of technological progress estimated from Yee's results were instructive in the sense that they are considerably lower than the 4.3% obtained by Yusoff.

MEASURING TECHNOLOGICAL PROGRESS IN RUBBER SMALLHOLDINGS: MICRO-ECONOMIC ANALYSIS

In an investigation that is almost similiar to Yee's, the author[5] measured technological change in Chinese rubber smallholdings by estimating the following models:

Model (i) $\log (TY) = b_0 + b_1 \log (\text{AREA}) + (b_2 + \delta_1 d_1) \log (\text{HR}) + (b_3 + \delta_2 d_2) \log (\text{FM}) + b_4 \log (\text{TREES}) + (b_5 + \delta_3 d_3) \log (\text{CAP}) + \delta_4 (d_4) + e_1$

Model (ii) $\log (AY) = b_0 + b_2 \log (\text{AREA}) + (b_2 + \delta_1 d_1) \log (\text{HR}) + (b_3 + \delta_2 d_2) \log (\text{FM}) + b_4 \log (\text{TREES}) + (b_5 + \delta_3 d_3) \log (\text{CAP}) + \delta_4 (d)_4 + e_2$

where TY is total yield of smallholding in kilogrammes per year

AY is average yield of smallholding in kilogrammes per hectare per year

AREA is size of smallholding in hectares

HR is number of tapping hours per hectare per year

FM is fertiliser and maintenance expenditure per hectare per year

TREES is number of trees per hectare

CAP is capital service flow ('expected yield per hectare per year') per year

δ_1, δ_2, δ_3, δ_4 are coefficients associated with dummies d_1, d_2, d_3, d_3, respectively where

$d_1 = d_2 = d_3 = d_4 = 1$ for 1978 smallholdings and

$d_1 = d_2 = d_3 = d_4 = 0$ for 1963/64 smallholdings

e_1 and e_2 are errors terms assumed n.i.d.

TABLE 1. RATES OF TECHNOLOGICAL PROGRESS BETWEEN DIFFERENT TECHNOLOGICAL STRATA

Technological stratum	Rates of technological progress between strata[4]	Average yearly rate of technological progress between strata[a]
Unselected seedlings (original technology introduced to the Malaysian rubber industry around 1876)		
	110.88%	1.85%
Pre-World War II high-yielding technology (1930-42)		
	9.34%, 14.38%, 16.01% (average = 13.25%)	0.83%
Immediate post-war high-yielding technology (1945-59)		
	14.58%, 18.15%, 19.91% (average = 17.55%)	1.10%
Recent high-yielding technology (since 1960)		

Source: Yee[4]

[a] Estimated by the author. As 1976 survey data were used, it was assumed that recent high-yielding technology was from 1960 to 1976, for calculating the annual rate of technological progress.

Capital service flow values for rubber smallholdings were derived in the following manner. Graphical yield profiles were first constructed for all the known rubber clones, from data contained in published records (various issues of *Planters Bulletin* of the Rubber Research Institute of Malaysia). These profiles represent the actual yield performance of various genetic materials as recorded by selected commercial estates throughout the country. Estates represent more ideal conditions perhaps than conditions present in rubber smallholdings. Assuming that there is proportionality between commercial estate yield and smallholding yield, a not unreasonable assumption, then given the age and clone type of a particular smallholding, its 'expected yield per hectare per year' estimated from the constructed yield profiles, will be a perfect substitute for the capital service flow per hectare per year. As long as we confine ourselves to multiplicative production functions like the Cobb-Douglas for example, the constant term will absorb whatever proportionality exists between commercial estate yield and smallholding yield. If, for example, the 'expected yield' is actually one-and-a-half times higher than smallholding yield on a per hectare basis, this differential will be absorbed by the constant term. The elasticities of production are not affected[6].

The '1978 smallholdings' refer to 355 Chinese rubber smallholdings in a random sample survey conducted by the author that year in the districts of Ulu Selangor and Ulu Langat in the state of Selangor. The '1963/64 smallholdings' refer to Chinese smallholdings in the Rubber Research

Institute of Malaysia survey, conducted in all the states of Peninsular Malaysia. There were 620 Chinese smallholdings in this survey. Thus the two samples were conducted over different areas at different points in time, but given that Chinese smallholdings in Selangor were not extreme cases compared to Chinese smallholdings in general, results obtained from comparison of these two surveys can perhaps be applied to smallholdings in general.

It is worth noting that using a Cobb-Douglas function, it is not possible to measure changes in the elasticity of substitution which always equals unity in the Cobb-Douglas case. Similarly, for measuring changes in returns to scale, the Cobb-Douglas function is unsuitable, as this particular function fails to distinguish returns to scale resulting from changes in the scale of operation from changes in returns to scale attributable to changes in technology. Thus using our models, we can only measure unambiguously technological progress arising from changes in the efficiency of a technology and changes in the ratios of the elasticities of production.

The empirical estimates of the models are shown in *Table 2.* The results indicate that the elasticity of production with respect to the capital service flow variable changed significantly between 1963/64 and 1978, while the intercept and other slope coefficients did not alter significantly. There is an 18.1% change in the slope with respect to the capital service flow, while the corresponding figure in the average

TABLE 2. ESTIMATES OF COBB-DOUGLAS MODELS

Parameter	Variable	Model (i)	Model (ii)
b_0	Intercept	0.8693	0.8729
b_1	AREA	0.8937*	−0.1036*
		(0.0239)	(0.0238)
b_2	log (HR)	0.2438*	0.2444*
		(0.0359)	(0.0357)
δ_1	dummy	0.0513	0.0279
		(0.1121)	(0.1114)
b_3	log (FM)	0.0894*	0.0895*
		(0.0102)	(0.0101)
δ_2	dummy	−0.0245	−0.0271
		(0.0261)	(0.0259)
b_4	TREES	0.4087*	0.4057*
		(0.0490)	(0.0487)
b_5	log (CAP)	0.0755*	0.0759*
		(0.0326)	(0.0324)
δ_3	dummy	0.1812*	0.1756*
		(0.0843)	(0.0838)
δ_4	dummy	0.5791	0.4998
		(0.3800)	(0.3778)
R^2		0.7051	0.3245
F		242.5059*	48.7253*

*Significance at 5% level
Figures within brackets are standard errors.

yield model is 17.6%. These changes clearly represent a capital-augmenting type of technological progress. While the 18.1% change over 1963/64 to 1978, equivalent to 1.2% annual increase, may seem low compared to the 4.3% obtained by Yusoff for the estate sector, it must be remembered that ethephon stimulation and fertiliser application were combined with improvements in genetic material in the aggregate variable K in Yusoff's analysis. In our micro-economic approach, increases in yield resulting from improvements in capital stock are separated out from increases in yield resulting from improved fertilisation and maintenance.

Thus the gap between our finding of 1.2% and Yusoff's of 4.3% is narrowed, considering the differences in assumptions.

Comparing the two sets of figures in *Table 3*, which shows the factor inputs used in rubber production, there has been an increase of 66% in the capital service flow variables, which works out to about 4.4% on a per year basis. There has been a 11.7% improvement in yield per hectare per year - an increase of about 0.8% per year. This 0.8% is a gross increase. Taking into account the effects of changes in factor combination, as done through our regression models, the improvement in capital-augmenting technological progress of 1.2% seems realistic. Empirical estimates of technical progress in manufacturing industries, on an annual basis, vary from 1% to 4.2%[7]. It is therefore inconceivable that technical progress in an agricultural industry, especially in smallholdings, can exceed the rate of technical change in manufacturing.

CONCLUDING REMARKS

Technological progress is commonly measured *via* aggregate production functions where capital and other factor inputs are defined in broad macro-economic terms. We approached technological progress from a micro-economic viewpoint. A Cobb-Douglas production function was fitted to a combined set of data comprising both the 1963/64 RRIM smallholdings survey and our 1978 survey with dummies to detect changes in the intercept term and the slopes for the various factor inputs. The main result obtained is that technological progress in rubber smallholdings is the capital-augmenting type. The rate of progress is estimated to be 1.2% per year compared with 4.3% cited in the literature.

TABLE 3. COMPARING MEANS OF SELECTED VARIABLES FOR 1963/64 RRIM SMALLHOLDINGS SURVEY AND 1978 SURVEY

Variables	1963/64 RRIM Survey	1978 Survey	Change (%)
Tapping hours per hectare per year (h)	492.03	304.10	−38.20
Fertiliser-maintenance expenditure per hectare per year ($)	161.76	197.52	+22.10
Number of trees per hectare	356.04	393.12	+10.42
Capital services flow per hectare per year (kg)	940.49	1567.03	+66.62
Age (years)	15.44	15.94	+3.24
Area of smallholding (ha)	2.87	4.69	+63.60
Yield per hectare per year (kg)	886.49	990.12	+11.69

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University of Agriculture, Serdang, Selangor, Malaysia *January 1984*

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