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THE CONSEQUENCES OF SMALL RICE FARM MECHANIZATION PROJECT

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MEASURING THE IMPACT OF MECHANIZATION ON OUTPUT

By

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ABSTRACT

The impact of agricultural mechanization on output will vary with the form of machine, the on-farm resource situation, season, region, soil type, etc. and the institutional structure (pricing conditions) of agriculture. The primary impact of mechanization will manifest itself in a changed farm input structure leading to possible output differences between mechanized and non-mechanized farms. Attributing that part of the output difference due to mechanization alone is however difficult for there are many confounding factors. A production function approach using covariance analysis (dummy variables) is described and this is applied to Philippine survey data and initial results presented. Linear isoquants showing rates of substitution between animal and machines during land preparation operations are also estimated. A power tiller day substitutes for 2.5 carabao days whilst a tractor day is equivalent to 4.6 carabao days.

INTRODUCTION

Agricultural mechanization in its many forms has brought far-reaching changes in farming structure over the past few decades in all developed countries; its effects are now beginning to be felt in many developing countries too. Within the former, mechanization has been associated with increasing farm size, migration of labor out of farming and the development of agriculture as a specialist economic activity as opposed to a subsistence one. New inputs of improved quality have been developed, modern management practices adopted and machinery inputs (capital) have substantially substituted for labor and animal-power inputs. The consequences of farm mechanization result from its interaction with the institutional structure of agriculture however and its introduction to the developing countries will not necessarily result in similar adjustments. Indeed one might argue that it is within the hands of the developing countries themselves to intervene and modify the impact of mechanization.

Before intervention however it is necessary to understand what the effects of different forms of mechanization are on such factors as output, labor demand and cropping intensity. The measurement of such effects is the immediate concern of this paper. The problem is one of disentangling cause from effect and while there have been significant increases in rice output over recent years in S. E. Asia, much of this is probably attributable to non-machinery technology with mechanization playing only an enabling role in the process. A counter view of other advocates of mechanization is to implicitly assume that its introduction will be directly output increasing. The issue resolves itself into an empirical question and it is not expected that the resulting impacts will be the same everywhere. Farm structures, tenure patterns, soils, prices, irrigation networks and institutional arrangements will vary from site to site. Such factors will both shift the underlying rice production function and shape the behaviour of rice farmers so that differential impacts will be observed for different situations.

Potential Output Effects

If the traditional power input (carabao plus associated implements) is a bottleneck or binding constraint to farm output goals, then the introduction of machinery technology may be expected to result in significant output increases. An increase in the input of power might show up in increased yields, an extension in the area cultivated, a release of land and other inputs formerly allocated to draft animals and improved cropping intensity. Quality aspects associated with the new source of power input such as deeper plowing, improved seed-bed preparation and faster operating times would add to the effects of the quantity increases.

At the micro experimental plot level, individual machinery cultivation effects have been observed[1] for a number of operations. However at the whole farm level and for more aggregated data, such effects become masked by changing farmer behaviour patterns and other qualitative influences. Indeed such factors as 'timeliness' and turnaround time' are extremely elusive concepts difficult to define, observe and measure and impossible to relate to the broader aggregates found in farm survey data. For example, in rice production such effects will not be observed solely in the wet season nor solely in the dry season but on a calendar year basis. Splicing the two seasons data together is not a feasible solution. Therefore we are left with measuring differences in cropping intensity, the incidence of multiple-cropping, etc. for which 'turnaround time' and 'timeliness' explanations are but two influences along with water availability, soil-types, weather and many other factors not particularly related to mechanization. King (1974) reported that 84% of the increase in cropping intensity for tractor adopters is explained by changes in irrigation and no evidence supports the hypothesis that increased intensity results from mechanized land preparation. Duff (1978) concludes his survey of recent evidence that the "actual impact of intensification through reductions in turnaround time is extremely hazy."

The question thus remains as to whether machinery is yield-increasing, output-increasing or quality-improving at the farm level. Are timeliness, increased power and other attributes of machinery technology actually used by farmers? Could not the same degree of timeliness be achieved by a combination of labor and traditional techniques? Does timeliness matter in any case? A whole series of issues arise; there are many factors to disentangle particularly at the aggregate level of farm survey data and we must be careful not to attribute to machines the effects of other techniques or inputs. A possible approach to this problem is to systematically introduce separate dummy variables into our economic relationships for each of the qualitative influences (irrigation, soil, region, mechanized or not) held to be important and to this approach we now turn.

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[1]See for example Orcino and Duff (1974) where 5 tillage treatments were experimentally assessed at 4 sites with variable soil and water characteristics. Differences in yield for different land preparation methods were statistically significant but quantitatively small. Incidentally the sites are similar to those reported on later in this paper.

Mechanization Relationships with Dummy Variables.

In an attempt to both identify and measure the effects that mechanization has had on such variables as output, cropping intensity and farm employment, we may hypothesize that relationships exist between these variables and other variables. Such relationships may arise out of economic and agronomic theory, for example labor demand functions or rice-fertilizer response functions, or be essentially pragmatic ones. However we should draw on theoretical constructs whenever possible in order to both specify the relationships (functional forms and variables to be included) and to provide prior restrictions on the signs and coefficients of the parameters within the relationships. Previous empirical studies are also a further source of prior restrictions.

In our case we might hypothesize, on the basis of both theoretical and empirical considerations, that the levels of cropping intensity, output and employment are functions of such variables as farm size, fertilizer use, crop protection inputs, irrigation technique, soil type, region, mechanization category, etc. plus some random error effects. The problem arises however as to how we measure some of these effects and incorporate them into the relationships. For some variables we have clearly measurable data, for example fertilizer use, labor inputs, etc. but for others (irrigation, soils, etc.) the effect is not readily apparent. With such a category of variables which may be considered to have a qualitative influence rather than a continuous, quantitative one the use of dummy variables (zero-one variables) is often an appropriate way to incorporate them into the relationship.[2] In this way, the absence or presence of such qualitative factors is allowed to modify the intercepts and/or slopes of the underlying relationship.

We would argue that the potential advantages of tractors in rice farming are essentially of a qualitative nature (deeper cultivation, more timely tillage, etc.) and that an appropriate way to incorporate the state of mechanization into our relationships is via a set of dummy variables. Agarwal (1980) adopted this approach, in contrast to Roy and Blase (1977-78), which has an additional advantage in that it circumvents the question of converting carabao power inputs into some corresponding tractor power units. Conventional significance tests may then be applied to the coefficients on the dummy variables or Chow tests performed. Such a procedure is carried out on a data set for tractors and power tillers in Nueva Ecija, Philippines, which is first described.

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[2] See Johnston (1972) pp. 176-207 for a fuller explanation.

The Nueva Ecija Tractor and Power Tiller Survey 1979.

In August 1979 a survey was carried out in Nueva Ecija into the use patterns of power tillers, tractors and carabaos by L. Roa, an IRRI research scholar. This survey followed up earlier work in that area by Yang in 1973. The study area essentially comprised 3 barrios - the barrios of Pulo and Baluarte, irrigated from the Peñaranda River Irrigation System, are characterized by deep and moderately deep soils respectively, Kapalangan is a rainfed barrio with ligher and shallower soils and, to include enough farms using animal power alone additional observations from the adjacent rainfed areas of Bungo and Mahidon were added to the sample. In all, 146 farms were in the survey, 41 in Baluarte, 46 in Pulo, 42 in Kapalangan and 17 in the adjacent regions. One hundred six farms have canal irrigated parcels, 12 pump irrigated parcels and 35 rainfed parcels including a few with multiple water sources. On the basis of land preparation data, twenty three farms were classified as being non-mechanized, 68 hired power tillers, 45 owned power tillers and 10 hired tractors. Tiller owners were located mainly in Baluarte and Pulo, tiller hirers were uniformly distributed across the 3 regions, tractor hirers in Pulo and Kapalangan and the carabao only users mainly in the rainfed regions.

Such a sample design creates problems at the outset in trying to unravel the contributions of mechanization for only 13% of the non-mechanized group were irrigators compared to 98% for tiller owners, 86% for tiller hirers and 70% for tractor hirers. Ninety-eight percent of farmer reported using modern varieties and 84% of the farms were leased with no significant variations across the classes of machinery users. Despite classifying into 4 groups with regard to the use of animal, tiller or tractor power for land cultivation, the ubiquity of the carabao should still be noted with 77% of machine-using farms also using a carabao at some stage in their farming operations. Six of the 10 tractor hiring farms also hire power tillers and consequently the 146 farms must be viewed as a continuum along which farmers use different combinations of animal and mechanical power in rice land cultivation. The salient features of the sample when grouped by type of machine user are shown in Table 1 for the wet season data 1977/78 and Table 2 for the dry season.

Summarizing the wet season data briefly, the carabao using farms have a much lower average yield/ha than the mechanized groups but much of this difference will be due to the mainly rainfed nature of these farms and a much lower application rate for fertilizer rather than a machinery effect per se. Land preparation time in machine or animal days per ha is over twice as much for animal-only using farms as it is for machine users but total preharvest labor shows little variation between animal and tiller users. Tractor hirers use a lower amount of preharvest labor. Postproduction labor for harvesting, threshing, etc. is significantly higher for the power tiller owners at 31.7 days/ha but this is obviously related to the much higher average yields of that group.

Broadly speaking carabao farms rely on hired labor for half their labor input compared to three-quarters for the mechanized groups and this is due to the latters dependence on hired labor both for land preparation and harvesting operations. The labor per farm is highest for the power tiller owning group but, on the basis of per ton of harvested rice, carabao farms have the highest labor input on account of their low yields. In the dry season the sample falls to 114 farms with only 4 farms in the non-mechanized group and 6 within the tractor hirers. The annual cropping intensity for these groups is consequently much lower than for power-tiller users the majority of whom have access to irrigation water. Yields and fertilizer use are generally higher in the dry season, the labor input per farm is similar between seasons but, because of higher dry season yields, labor per ton of output falls considerably.

Model Specification and Results

In order to assess the impact of mechanization on such factors as output, cropping intensity and labor use for the Nueva Ecija farm sample, a series of alternate models was specified and the main results are presented in Tables 3 to 6. Variations across the whole sample are explained rather than grouping the data by mechanization category with dummy variables allowing the functions to shift across groups. The sample size does however vary for different specifications largely as a result of fewer farms planting in the dry season and the problem of zero input users when using a logarithmic function. Model specifications and results are summarized below.

1. Cropping intensity is hypothesized to be a function primarily of irrigation, farm size, mechanization and region and results of 2 alternate models are shown in Table 3. Ex-ante irrigation is expected to have a large positive effect, larger farms to be less intensive and because of 'timeliness' and 'turnaround' considerations use of power-tillers and tractors should have some positive influence. The reported results bear out these prior beliefs with irrigation and machinery dummies plus a farm size variable explaining 69% of the variation in cropping intensity across 146 farms. The coefficients all have the expected signs, irrigation and power-tiller owner dummies are statistically significant at the 1% level and the power-tiller hirer dummy is significant at the 5% level. In the alternate specification however 3 regional dummies, the irrigation dummy and farm size variable explain 71% of the variation, all are significant at the 1% level and as a consequence it is clearly not certain that we have distinguished the mechanization effect from the regional influences at work. The base for the regional dummies is the 17 farms not in the barrios of Baluarte, Pulo or Kapalangan.

2. Labor use relationships: Labor use was expected to be determined by such variables as farm size, fertilizer use, mechanization status, and irrigation. Alternate formulations were specified for both total farm labor use and also when disaggregated into family and hired categories. Numerous equations were estimated, the majority of which produced surprising results which were also poor in a statistical sense. Table 4 reports some results of logarithmic relations. Farm size is the major explanatory variable in equations explaining inter-farm variations in reported labor use yielding an adjusted R^2 of 0.49 for the wet season and 0.45 for dry season data. The mechanization variables have the expected negative signs but are insignificant in contrast to Cordova's (1979) positive and significant power tiller coefficient but the results are otherwise poor. Variation of Postharvest labor is explained by yield differences with an adjusted R^2 of 0.31 for the wet season and 0.30 for the dry season. Expressing the labor input on a per ha basis, it proved impossible to arrive at any satisfactory results.

3. Production functions - the results of conventional Cobb-Douglas production function estimation are reported in Table 5 for both wet and dry season data with area incorporated within the model and with all variables expressed on a per ha basis. For the wet season only 36% of the variation in output is explained by the function specified but all variables have the expected signs. The fertilizer variable, power tiller owner and tractor hirer dummies are significant at 1% level and the power tiller hirer dummy approaches significance at that level. Land, labor and pesticide inputs are non-significant and the coefficients sum of 0.79 indicates decreasing returns to scale. An alternate specification on a per ha basis yields significant fertilizer/ha and labor/ha variables but both the irrigation and mechanization dummies are insignificant and only 18% of per ha output differences is explained by the function.

Results for the dry season data are somewhat better, labor, fertilizer and all 3 mechanization dummies are significant and 62% of the variation in output is explained by the function. The coefficients sum of 0.927 signifies weak decreasing returns to scale and again the pesticide variable is insignificant. The per ha basis function likewise yields plausible results with labor/ha and fertilizer/ha inputs significant along with the mechanization and irrigation dummies. The per ha specification whilst removing one possible source of collinearity between farm size and other variables does however introduce the implied restriction of constant returns to scales and as is usually the case R^2

falls from 0.62 to 0.44. It is not however strictly legitimate to use R^2 to compare the functions when they have different dependent variables.

The reported functions indicate that mechanization does make a significant contribution in explaining output variations across the sample of farms. Omission of variables for the managerial input and additional capital inputs could impart a specification bias to the results which are in addition fraught with other well-known production function estimation problems. They do however, give some quantitative measure of how mechanization may shift the intercept term in Cobb-Douglas functions and for both seasons the coefficient on tractors is greater than that for power tiller as expected.

4. Animal-machine Substitution. Given the 3 different sources of power on the sample farms and the fact that most farms use more than one power source during land preparation operations, it may be hypothesized that there is some rate of direct substitution between carabao, power-tiller and tractor. Data collected on the number of days spent plowing, harrowing and levelling by the various power sources enables us to hypothesize that the area prepared will be a function of the 3 power inputs. Consequently a relation of the form below was estimated:

$$H = a + b_1 C + b_2 PT + b_3 T + u$$

where H is the area of land prepared in hectares

C is carabao days

PT is power-tiller days

T is tractor days

u is a statistical error term and a, b_1, b_2, b_3 are

coefficients to be estimated. Such a function assumes direct substitutability between the three different power inputs and across the plowing, harrowing and levelling operations. Somewhat unrealistically it implies a direct substitution between say plowing 1st pass using power tiller and harrowing 3rd pass by carabao since the data was aggregated (unweighted) across the six land preparation operations. Nevertheless we anticipate a priori that:

$$0 < b_1 < b_2 < b_3 < 1$$

Verbally, we expect a tractor day to be greater than a power tiller day which in turn is greater than a day's carabao operation. Results of the regressions are shown in Table 6. For the wet season, apart from a moderate goodness of fit ($R^2 = 0.44$) the results are as anticipated with all coefficients significant at the 1% level with the correct orders of magnitude. They imply that a power tiller day is equivalent to 2.53 carabao days and 0.54 tractor days whilst a tractor day will substitute for 4.64 carabao days. Essentially this approach estimates linear isoquants between the various power sources and non-linearities will be examined at the next stage in the analysis. Incorporating three regional dummies for soil types fails to improve the goodness of fit of the equation although that for Pulo has a significant negative coefficient. The goodness of fit is little altered too when the carabao - only using farms are omitted from the sample (n = 123). Analysis of the dry season data is however somewhat less promising, R^2 falling to 0.22. This method does shed some light on substitutability between power inputs and will be further developed.

Conclusions:

The paper has suggested possible regression routes with which to analyze data from the mechanization consequences study. Dummy variables are a key technique in the approach and their use is recommended on whole samples rather than grouping the data according to mechanization status. The latter is fraught with difficulties and simply putting say a power input variable into a set of tractor-using farms merely measures the impact on output of differences in tractor use on such farms - not surprisingly such a variable is often non-significant. Results presented using Philippine data indicate that mechanization contributes to cropping intensity increases given irrigation, no major effect could be found on labor use, mechanization dummies significantly shift the intercept terms in Cobb-Douglas production functions and that it is possible to estimate the rates of substitution between the various land preparation power sources. However the analysis is still in its infancy and requires much further development. Additional theoretical constructs must be incorporated as a next stage.

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Table 1. Characteristics of sample farms by type of mechanization, Nueva Ecija, Philippines, wet season, 1977-78.

	Un-mecha-nized	Power tiller owners	Power tiller hirers	Tractor hirers
No. of farms	23	43	70	10
Average size (ha)	3.26	2.98	2.24	3.25
Yield/ha (kgs)	1527.2	3246.9	2774.8	2391.6
Preharvest labor (m.days/ha)	47.15	48.98	51.27	34.89
Postproduction labor (m.days/ha)	18.36	31.7	22.0	17.3
Percentage hired labor	51	73	71	75
Land preparation (machine or animal days/ha)	15.9	4.9	6.2	5.5
Labor/farm (m.days)	213.6	241.3	164.3	169.8
Labor/ton (m.days)	43.1	24.9	26.2	21.5
Fertilizer/ha (₱)	239.0	422.9	421.7	285.8
Pesticide/ha (₱)	80.7	196.6	144.6	65.4
Cropping intensity	1.15	1.95	1.83	1.60
No using carabao	23	37	51	7

Table 2. Characteristics of sample farms by type of mechanization Nueva Ecija, Philippines, Dry season, 1977-78.

	Un-mecha-nized	Power tiller owners	Power tiller hirers	Tractor hirers
No. of farms	4	42	62	6
Average size	2.63	2.99	2.26	2.42
Yield/ha	1870.8	4283.9	3947.2	3815.2
Preharvest labor (m.days/ha)	39.8	48.4	48.2	42.3
Postproduction labor (m.days/ha)	14.9	31.5	23.1	18.8
Percentage hired labor	37	73	71	79
Land preparation (machine or animal days/ha)	9.7	5.4	5.8	4.1
Labor/farm (m.days)	143.5	250.8	163.6	147.5
Labor/ton (m.days)	29.2	18.7	18.06	16.0
Fertilizer/ha (₱)	281.8	574.1	588.9	393.5
Pesticides/ha (₱)	67.5	217.3	120.8	114.2
No using carabao	4	26	42	1

Table 3. Results of cropping intensity linear regression analysis, dependent variable cropping intensity.

Independent variables		
Area (ha)	-0.045 (0.168)	-0.036* (0.015)
Dummy - irrigation	0.674* (0.059)	0.633* (0.059)
Dummy - power tiller owner	0.209* (0.075)	
Dummy - power tiller hirer	0.136 (0.068)	
Dummy - tractor hirer	0.071 (0.095)	
Dummy Baluarte		0.325* (0.083)
Dummy Pulo		0.269* (0.085)
Dummy Kapalangan		0.200* (0.074)
Constant	1.219	1.124
Sample size	146	146
Adjusted R^2	0.698	0.713

Figures in parentheses are standard errors.

*Significant at 1% level.

Table 4. Estimated labor relationships: all variables in logarithmic form.

Dependent variable :	Preharvest labor (days)		Postharvest labor (days)	
	Wet season	dry season	Wet season	dry season
Independent variables:				
Land (ha)	0.703*	0.736*		
	(0.074)	(0.086)		
Fertilizer (peso)	-0.026	0.003		
	(0.059)	(0.083)		
Dummy-power tiller owner	-0.057	0.008		
	(0.145)	(0.174)		
Dummy-power tiller hirer	-0.098	-0.061		
	(0.142)	(0.169)		
Dummy-tractor hirer	-0.324	-0.152		
	(0.182)	(0.210)		
Dummy-irrigation	0.102	0.327*		
	(0.133)	(0.152)		
Output harvested (kgs)			0.458*	0.491*
			(0.064)	(0.057)
Constant	4.307	3.756	0.062	-0.331
Sample size	105	105	112	112
Adjusted R^2	0.497	0.450	0.309	0.394

Figures in parentheses are standard errors.

*Significant at 1% level.

Table 5. Estimated Cobb-Douglas Production Functions; dependent variable rice harvested (kgs).

Independent variables	Wet season		Dry season	
		Per ha basis		Per ha basis
Land (ha)	0.224 (0.175)		-0.099 (0.132)	
Labor (man days)	0.277 (0.179)	0.409* (0.152)	0.481* (0.143)	0.307* (0.126)
Fertilizer Cost (pesos)	0.234* (0.089)	0.184* (0.092)	0.443* (0.087)	0.335* (0.087)
Pesticide expenditure (pesos)	0.060 (0.077)	0.057 (0.072)	0.102 (0.056)	0.100 (0.052)
Dummy - power tiller owner	0.457* (0.223)		0.428* (0.190)	
Dummy - power tiller hirer	0.409 (0.213)		0.463* (0.178)	
Dummy - tractor hirer	0.581* (0.269)		0.658* (0.221)	
Dummy - mechanization		0.356 (0.254)		0.471* (0.197)
Dummy - irrigation		0.210 (0.201)		0.390* (0.159)
Constant	4.806	4.226	2.504	3.487
Sample size	113	110	113	110
Adjusted R^2	0.356	0.182	0.623	0.446

Figures in parentheses are standard errors.
* Significant at 1% level.

Table 6. Results of land preparation - source of power relationships; linear function, dependent variable, area of land preparation (ha).

Independent variables	Wet season		Mechanized farms only	Dry season	
Carabao days	0.036* (0.003)	0.032* (0.004)	0.061* (0.008)	0.022* (0.010)	0.026* (0.011)
Power tiller days	0.091* (0.018)	0.093* (0.012)	0.101* (0.012)	0.061* (0.010)	0.058* (0.010)
Tractor days	0.167* (0.054)	0.185* (0.054)	0.158* (0.052)	0.086 (0.054)	0.086 (0.054)
Dummy Baluarte		-0.375 (0.328)			1.164 (0.878)
Dummy Pulo		-0.657* (0.322)			0.990 (0.876)
Dummy Kapalangan		-0.553 (0.292)			0.747 (0.876)
Constant	1.475	1.971	1.278	1.674	0.716
Sample size	146	146	123	114	114
Adjusted R^2	0.439	0.449	0.437	0.225	0.238

Figures in parentheses are standard errors.

*Significant at 1% level.

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