AFRICAN RURAL EMPLOYMENT RESEARCH NETWORK

African Rural Employment Paper No. 6

A FRAMEWORK FOR RESEARCH ON THE ECONOMICS OF FARM MECHANIZATION IN DEVELOPING COUNTRIES

by

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1973

THE AFRICAN RURAL EMPLOYMENT RESEARCH NETWORK

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This paper has been developed as part of a three year study of rural employment problems in Africa which is being financed under an AID/Washington Contract (AID/csd 3625) with the Department of Agricultural Economics at Michigan State University.

April, 1973

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I. INTRODUCTION

One of the important decisions facing the developing countries is that of determining the most economically and socially desirable rate and type of farm mechanisation. This decision is especially difficult in light of the limited cross sectional or time series research on the impact of farm mechanisation on output, income, employment and income distribution, and in light of growing unemployment and underemployment in many developing countries.

A review of the literature on mechanisation reveals sharply divergent policy prescriptions among engineers and economists on mechanisation strategies in developing countries. There is now ample evidence that engineers and economists are "talking past each other" on the mechanisation issue. For example, economists frequently use catchy phrases such as "premature mechanisation" and the "paradox of mechanisation in labour abundant economies" while agricultural engineers often advance the concept of a "mechanisation ladder". It is obvious that such slogans are inadequate for national policy analysis.

We shall attempt to step back from the debate between economists and engineers and concentrate almost exclusively on the strengths and shortcomings of economic research on farm mechanisation in developing countries.

The purposes of this paper are to:

1. Outline a tentative framework for analysing the social and economic implications of farm mechanisation in developing countries.

2. Specify major types of short, medium and long-term policy decisions on farm mechanisation and needed research for improving these decisions.

3. Critically review selected economic studies on farm mechanisation in terms of research methodology and policy findings.

4. Suggest needed redirection in research on farm mechanisation in order to more adequately guide policy makers.

The wide divergence of opinion among researchers on the desirability of mechanisation in any one country is illustrated by the following quotations.

1. Pakistan: (There should be) ...an expansion of tractors to meet the minimum 0.2 h.p./acre goal at the earliest (time), 1985 or earlier. This requires a minimum increase at a 12 percent compound rate starting with 4,000 tractors per year (averaging 35 usable h.p.) in 1966. Giles [1967-b], p. 22.

   (If Giles' recommendation were implemented) ...in 1975 the direct costs to society...would be about 330 million rupees and the direct benefits would be around 200 million rupees... Similarly for other years direct social benefits would be considerably smaller than direct social costs. Moreover, the indirect social costs, mainly arising from throwing large numbers of farm labourers out of employment, may be considered much greater than the possible indirect benefits. Bose and Clark [1969], p. 294.

2. Indian Punjab: In balance there seem to be few arguments, logic or facts that should cast doubts on the economic feasibility of substituting totally inefficient animal draft power with mechanical power...creating more demand for human labour, and also improving its productivity and wage rates as well as productivity and returns to all other factors of production. Johl [1970], p. 32.

   Annual hired labour continued to increase between 1955 and 1970, but it is expected that by 1980 the demand for hired labour in field crop production will all but disappear. This result follows from the projected increase in the supply of family labour combined with increasing mechanisation of activities performed during the labour bottleneck seasons. Singh and Day [1972], p. 9.

3. Colombia: Our studies show a need for approximately 300,000 two-wheel 8 to 12 h.p. tractors and 83,000 four-wheel tractors, using 30 to 40 h.p. as a basis of calculation, for the mechanizable land presently in production.

University of Nebraska [1970]*.

Most other types of mechanization, in particular post-planting operations and the harvesting of crops other than rice, should not be encouraged for the present because they displace too much labour in relation to their benefits... No attempt should be made to de-mechanize, but the present tractor park is probably sufficient for mechanization of soil preparation and planting, and future imports should therefore be limited to replenishment needs.

Ministry of Agriculture [1971]*.

Withdrawing the subsidy to farm mechanisation would both improve the distribution of income and, as a bonus, better allocate the economy's existing resources. A tax on machinery use or a higher interest rate would remove this subsidy. Polarisation of the rural economy rather than modernisation is the most likely effect of a continuing subsidy.

Thirsk [1972-a], pp. 53-54.

4. Ghana: ...machines so greatly increase the efficiency of the productive farm labour that in spite of the tremendous accumulation of labour in non-productive jobs, the nation as a whole remains productive and solvent.

Buchele [1969], p. 18.

It is extremely risky to devote a large proportion of scarce material and personnel resources in efforts to mechanize a small fraction of the country's farmland when it is not sure that these efforts will really result in an increase in net output.

de Wilde, et. al., [1967], p. 130.

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*Quoted by Abercrombie [1972], pp. 41-42.

There are many reasons why researchers have reached such divergent positions as shown in the above quotations. First, research on mechanisation has at least three different aspects: technical, economic and sociological. Technical research by an engineer generates physical input-output information on each machine or system of machinery, e.g., hand labour takes 22 man hours to prepare an acre of land in Malawi whereas an ox-team takes 13 animal-team hours [Gemmill, 1971]. The economist uses the technical information to assess the costs and benefits of the alternatives to the farmer and to the country. When the economic analysis is complete, a sociological analysis of the implications of the alternative mechanisation strategies remains. For example, would increased mechanisation lead to the rapid break up of rural families, increased rural-urban migration, political unrest, etc.? Because the engineer, economist and sociologist have different disciplinary objectives, they often reach very different conclusions. The previous quotations from engineers and economists highlight these differences.

Second, even within a single discipline, different conclusions may result from using alternative sets of assumptions or data. The failure to recognise the difference between financial and economic analyses is still a major cause of confusion among economists. This distinction will be explained thoroughly in Section IV of this publication.

Third, when research findings are presented, many different policy-prescriptions may be derived. This is especially true when the

research is concentrated in one district and only a few alternative technologies are considered. However, government requires some policy-prescription for the whole country.

The major concern of this paper is not to contrast the findings of economists, sociologists and engineers, but to demonstrate that economists have reached divergent conclusions because of their alternative assumptions and because they have made somewhat speculative policy prescriptions based on small-scale analyses. Section II begins by describing in a general manner how mechanisation or other technological changes in agriculture affect social and economic conditions in the village and in the country as a whole. A framework is developed which provides a background for the whole paper. Next, in Section III, the decisions which government has to make concerning farm mechanisation are divided into short, medium and long-term classes and the types of economic research which may be relevant for each class of decision are examined. The major part of the paper, which is a review of economic studies of farm mechanisation in developing countries, follows in Section IV. The intent of the review is to discover how fully such studies have met the needs of policy-makers. Finally, in Section V, the paper is summarised and some needed redirections of economic research for improved policy decisions on farm mechanisation are proposed.

II. FRAMEWORK

(For viewing the social and economic implications of mechanisation)

The introduction of new technology into agriculture has many interrelated social and economic implications. In order to identify the data needed for

sound decision-making and to demonstrate the narrow conception of much of the current research on technological change, the authors set out below a general equilibrium framework. The framework is tentative. The authors are not suggesting that research on new technologies needs to measure every possible implication. However some researchers (e.g., Thirsk, 1972-a) have made progress in formalising the relationships described in this section.

Our conception, which is illustrated in Figures 1 and 2, divides the implications of mechanisation into those occurring in the country as a whole and those occurring in the village. At the top of Figure 1, "Country-wide Framework," are typical macro-economic objectives--employment, income and its distribution and the level of foreign exchange available. In the central box is the decision unit, in this example the village. It is this unit which is expanded in the village-level framework (Figure 2).

The choice of technology and of product-mix (diamond boxes in Figure 1) interact with the markets for products, labour and physical inputs (square boxes) and affect employment, income and its distribution and the level of foreign exchange in the country (top of Figure 1). A description of the action of Figure 1 begins with the product market (at the extreme right).

Given product prices (P_Q), the price of labour (P_L) and input prices other than labour (P_K), the decision unit chooses some mixture of products and technology as well as deciding on a certain level of labour utilisation. The resulting production is either consumed directly in the village or becomes marketed surplus. Given the product prices (P_Q) (incorporating lags, etc.), a certain value of output is achieved and a certain income is received. Meanwhile, the decisions on labour have

Figure 1. Country-Wide Framework

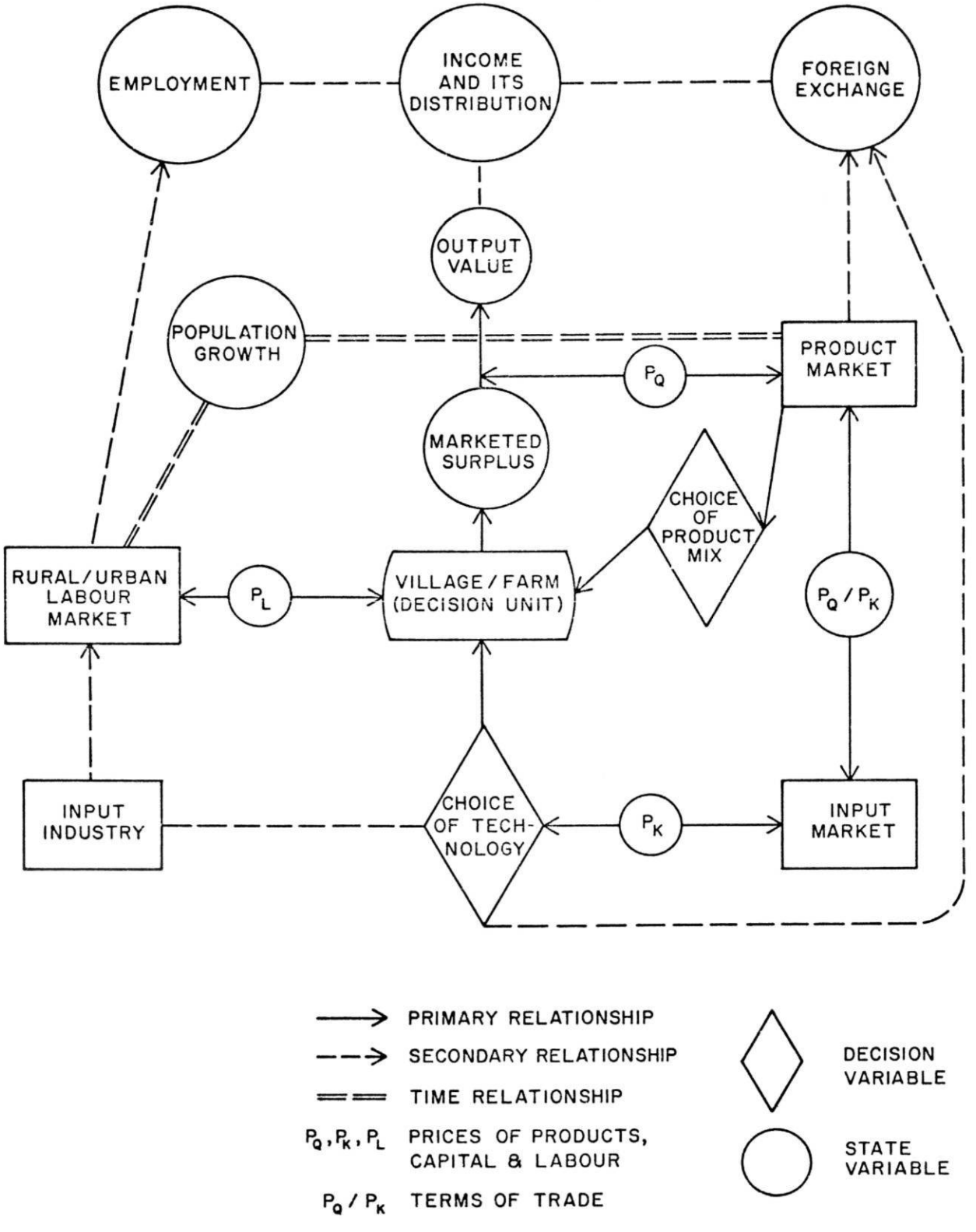
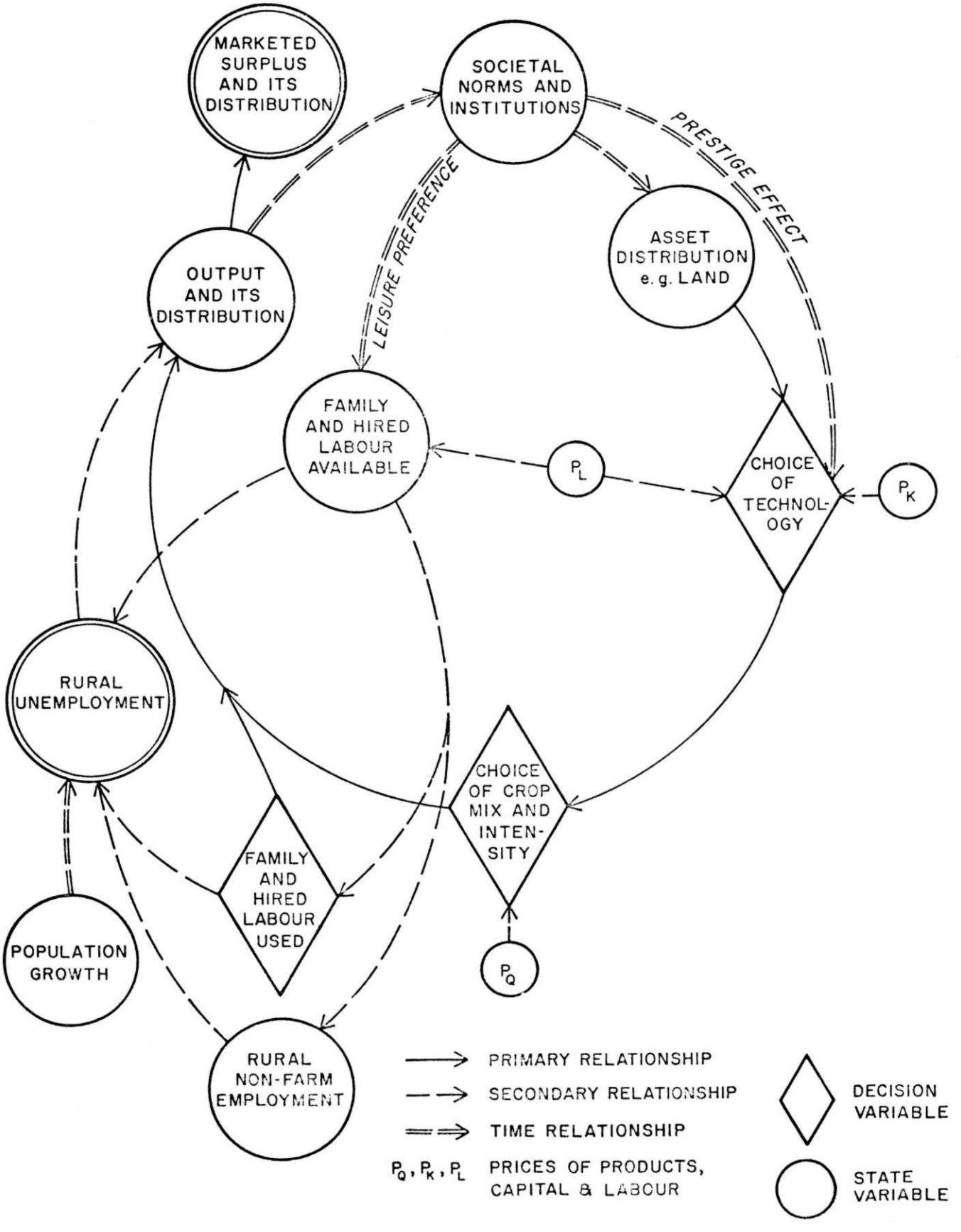


Figure 2. Village-Level Framework



affected the rural-urban labour market both directly and through a linkage with the input industry (bottom left box). Similarly, choice of technology and product have affected foreign exchange. By aggregating, the states of the three goals of employment, income and its distribution and foreign exchange are reached. Over time, population grows affecting labour and product markets, changing the state of most of the variables described.

Figure 2 is the village-level conception.[1/] To interpret Figure 2, begin with an asset distribution in the village: land, labour and wealth (at the top right-hand corner of the diagram). Given this asset distribution and prices of labour, other inputs and products, the individual farmers in the village choose crop mixtures, types of technology and levels of labour utilisation (around the main circle in Figure 2). Together these decisions determine output and its distribution between family and hired labour. Labour which is not utilised in agriculture may seek rural nonfarm employment, migrate or remain unemployed.

There are two important time-linkages in Figure 2. Population growth (at bottom left of the diagram) affects the level of employment or unemployment, hence the price of labour, the level of consumption and the choice of technology and crop mixture. The second time-linkage is behavioral. The distribution of output (via a wealth effect) and the choice of technology (via a prestige effect) change the village norms and the distribution of power. These changes, in turn, may affect village institutions, such as

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[1/] Our village-level conception is similar to that of Gotsch [1972] and owes much to him. We have chosen a village rather than a farm as our basic unit as there is some evidence that adoption of new technology is concentrated in certain villages [Hrabovsky and Moulik, 1966]. Using a village unit, changes in the local power-structure, norms and institutions can be readily observed.

the land tenure system. A few individuals may be able to displace others from their land, either directly, through such an action as the eviction of share-croppers, or indirectly, through some more subtle means such as the "calling-in" of debts for which the poor must forfeit some of their land.[2/] Two norms likely to change are the number of hours worked and the type of labourworking (men, women or children). These changes will then affect the labourmarket in the village (see arrow marked "leisure preference").

The reasons for believing this framework to be important will now be summarised. A single change in technology, if widespread, may have far-reaching implications for a whole society. It is often insufficient to merely observe the production aspects of technological change when wider social outcomes are equally important. One needs to incorporate more general behavioral relationships into research than at present occur in economic studies. It will be argued in this paper that most economic studies of mechanisation have captured only a few of the implications in Figures 1 and 2 and that a wider perspective is essential for relevance to policy-making. In making such a framework operational the problem of aggregation bias in the derivation of macro results from micro data awaits further research. However, as we shall see in the review, Wayne Thirsk [1972-a] has made such a framework operational at the aggregate level for analysing short-term policy-decisions in Colombia and Carl Gotsch [1972] has used such a framework at the village level to compare and contrast

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[2/] Another example of the type of institutional change in the village with which we are concerned was observed by one of the authors in Malawi, where a village cooperative for vegetable marketing was forcibly taken over by a larger landowner, who then wielded his monopsonistic power to the disadvantage of the other farmers.

the impact of new technology in rural areas in Pakistan and Bangladesh.

III. SHORT, MEDIUM AND LONG-TERM POLICY DECISIONS ON FARM MECHANISATION AND RESEARCH NEEDS

Types of Policy Decisions

Governments of all societies are concerned with the rate and type of farm mechanisation being introduced. As evident from Figures 1 and 2, the choice of mechanical technology can influence the society being established through its effects on rural-urban migration, employment, output and income-distribution. In most developing countries, the decision on whether to mechanise or not is ultimately made by thousands of small farmers. Government has numerous short, medium and long-term policies at its disposal which influence the profitability of mechanisation to the individual farmer. We define short-term policies as those which directly affect mechanisation. For example:

1. Inclusion of mechanisation in government agricultural projects;
2. Subsidising tractor-hire services;
3. Subsidising credit for machinery purchases;
4. Removing or imposing tariffs on imported machinery, spare parts and fuel; and
5. Taxing locally produced machinery and spare parts.

It is assumed that in the short-term mechanisation will not affect the prices of inputs or outputs, i.e., it will be marginal in its impact.

We define medium-term policies as those which affect mechanisation

more indirectly and are less immediate in their impact. Examples of medium-term policies are:

1. Subsidising the prices of certain products;
2. Minimum wage legislation; and
3. Encouraging domestic machinery manufacture through government investment.

It is assumed that in the medium-term mechanisation affects product prices, the wage-level of labour, rural-urban migration and the distribution of wealth in a society, i.e., in the medium-term almost all of the variables in our framework are affected.

Long-term policies are the continuation of short and medium-term policies over a period of several decades. Government has some vision of the type of society which it would like to build through its long-term development strategy. To this end it has, either explicitly or implicitly, long-term policies which are as greatly influenced by political philosophy as by simple economics. One such long-term policy concerns the general importance attached to farm mechanisation.

An example may clarify this conception of short, medium and long-term policies and show how they interact. Russian economic development was based on the Marxist belief that agriculture and industry would be simultaneously industrialised. Hence Stalin developed a long-term policy of large-scale mechanisation for agriculture. This policy was implemented in the short-term, through the provision of subsidised tractor-hire services and subsidised credit for cooperative machinery purchase, and in the medium-term through heavier taxation and lower product-prices for peasants who refused to join the mechanised collective farms.

Types of Policy Research

Different kinds of research may be suitable for evaluating the costs and benefits of the short, medium and long-term policies outlined above. The longer the time horizon and the larger the sector of analysis, the more variables to be measured. Thus, more comprehensive research is necessary for making medium-term decisions than for making short-term decisions. For example, the promotion of tractor-mechanisation on a government rice-growing project (short-term decision) is not likely to affect the price of rice. However, building a factory to produce tractors and imposing minimum wage regulations (medium-term decisions) are likely to be far-reaching in their implications including, possibly, an expansion in rice production, a consequent decline in the price of rice and a reduction of employment.

Table I classifies some of the methodologies used by economists to study mechanisation in developing countries.[3/] The table is divided into three columns dealing, respectively, with economic studies of the short-term, medium-term and long-term implications of mechanisation. The different kinds of policy questions which are addressed under these time-horizons have been discussed previously. Any study which has dynamic aspects as a major component has been placed under medium-term, as have studies concerned with secondary effects such as employment in machinery industries. Empty boxes are simply those in which we have found no study, such as a perspective (long-term) study in one local area.

The table reveals that the most popular studies have been short-term

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[3/] A bibliography is available in the appendix. Note that any classification is somewhat arbitrary since it partitions a continuous variable into discrete boxes.

Table 1. Classification of Economic Studies of Farm Mechanisation in Less Developed Countries[a/]

	Short-term (Static)				Medium-term (Dynamic)			Long-term (Perspective)	
	Cost-Benefit	Cross-Section	Linear Programming	General Equilibrium	Budgeting	Programming	Simulation	Historical	Instrumental
Local	Baldwin [1957] Chancellor [1969] Dalton and Enikwaw [1971] Ellis [1972] b/ Green [1971] b/ Kolawole [1972] Laurent [1968] Lidman [1968] b/ Lord [1963] Peacock [1967] Purvis [1968] Renaut [1966] Van Wersch [1968] Weil [1970] Yudelman [1971]		Ahmad [1972] Clayton [1965] Gotsch [1973-a]						
Regional	Chopra [1972] Gemmill [1971]	Donaldson and McInerney [1973] Inukai [1970] Johl [1970] Rao [1972]	Panagides and Ferreira [1970] Vaurs [1971]		Singh and Billings [1971]	Singh and Day [1972] Singh and Ahn [1972]		Day [1967]	
Countrywide	Bose and Clark [1969] b/ Kaneda [1969] b/ Timmer [1972-a] b/ Weitz-Hettelsater Engineers [1971]			Thirsk [1972] Sanders [1973]	Johnston, Cownie and Duff [1970] Johnston and Kilby [1972]		Johnson, et. al. [1971] Rossmiller, et. al. [1972]	Jasny [1936] Kautsky [1900] Marx [1966] Miller [1970] Mesa-Lago [1971] Roberts [1972] Wheelright and McFarlane [1970] Whetham [1970] White [1964]	Gotsch [1972] Schmitz and Seckler [1970]

a/ We include only those cited in the text.
b/ These cost-benefit studies were economic, rather than just financial in nature (see text for explanation).

studies in one district (local) and long-term studies of whole countries. Short-term research requires few resources to reach some fairly firm conclusions for a small area such as a single district. The lone economist may be capable of conducting such a study. At the other extreme, long-term research tends to be more qualitative than quantitative and, therefore, relatively inexpensive. Long-term studies have generally been concerned either with explaining the historical importance of mechanisation within some doctrine such as Marxism, or with examining mechanisation in developed countries as a case study in economic history.

Only a few studies lie in the medium-term category, most of these being regional in their level. There are several reasons why medium-term research on mechanisation has been less popular than short or long-term research. First, it is more difficult to predict the medium-term effects of mechanisation than its short-term effects. As the time horizon is increased, the probability of making mistaken predictions increases. Second, methodologies for medium-term research are not yet well developed. Third, because the impact of medium-term policies is more difficult to measure than that of short-term policies, it is necessary to study an entire region or country to obtain accurate predictions on which to base policy decisions.

A classification of economic research on farm mechanisation has been presented and a critical examination of the studies themselves will be developed in the section which follows.

IV. REVIEW OF ECONOMIC STUDIES OF FARM MECHANISATION

Introduction

Assuming an engineering analysis is complete, several methodologies can be used to conduct the economic analysis. Theoretically the following are necessary steps in economic analysis. First, it is not possible to assess the advantage of new strategies without carefully defining the present situation. For the question of choice of technology, the existing farm size, tenure, output, income, technology in use, etc. for all regions and districts must be studied carefully. This information is sometimes available from sample surveys of agriculture.

The next step is to define the possible future states of the society. What farm sizes and types of tenure are possible? What technologies are available or may become available and at what prices? What would be the effects of each possible mixture of farm size, tenure and technology on output, employment and income distribution?

Finally, one cannot simply compare future states with the present state but must define that policy-set which will bring about a certain time-path to the future state. This time-path will depend on variables such as the rate of diffusion of new technology, population growth and migration, and product and factor prices.

These theoretical steps in an economic analysis roughly correspond to data collection, economic analysis and policy implications. The type of analysis and implications depend intimately on the type of data collected, therefore data collection will be discussed briefly before returning to the central themes of economic analysis and policy implications.

Data Collection

It is not easy to separate the effect of farm mechanisation from the effects of other factors such as increased fertilizer, water, improved seed, better management or even a change in land tenure. The intensity of data collection will depend on the importance attached to separating such individual effects. If one is interested in discovering whether subsidised credit for mechanisation has led to a lower GNP than could otherwise have been obtained, an aggregate type of data is required such as the National Accounts of a country.[4/] If, however, one is interested in the impact of mechanisation at the farm level, it is necessary to conduct a farm management survey. The details of this survey-technique are well known and may be reviewed in Spencer [1972], Norman [1973], Yang [1965], Cleave [1970] and Chabrolin [1968]. The complexity of the survey depends on the budget available and the quality of the data needed.

Inevitably, many feasible technologies are not presently in use and cannot, therefore, be surveyed. The researcher then has no option but to specify these alterantives using "synthetic" data gathered from a number of sources, including surveys in other countries and experimental stations' results.

Following data collection, either a financial or an economic analysis can be completed. The differences between these two types of analysis are often a source of confusion between economists and engineers and therefore a brief description of these differences will be presented next.

[4/] For example, see Thirsk [1972-a].

Financial Versus Economic Analysis

A distinction must be made between the profitability of a change in technology to an individual (private or financial profitability) and the profitability of that change to the country as a whole (economic profitability).[5/] In an economic analysis all input and output prices are changed from the market levels, which are used in the financial analysis, to their true economic levels (often called "shadow" prices). Some examples may illustrate how to use shadow prices.

In Colombia mechanisation is encouraged by the provision of credit for machinery purchase at 10 percent interest; the unsubsidised interest rate is approximately 20 percent [Thirsk, 1972-a]. In the financial analysis, a 10 percent rate would be used. In the economic analysis, a 20 percent rate is needed. Another example is found in Brazil where the price of wheat has been subsidised at twice the world market price [Singh and Ahn, 1972]. Such subsidisation represents a cost to the country; an estimated unsubsidised price should be used in the economic analysis. A third example concerns labour as an input. In many countries minimum wage laws have been enacted in order to raise the income of hired labourers. The use of an artificially high wage in the economic analysis would bias the conclusion in favour of more capital and less labour-intensive technologies. The shadow price or opportunity cost of this labour in the economic analysis will probably be lower than the minimum wage.

5/ For a fuller exposition of the difference between financial and economic analysis, see Gittinger [1972].

Each of these differences between financial cost and economic cost is called a factor-price distortion.[6/] In relation to mechanisation, such distortions also include an overvalued currency exchange-rate so that capital-imports are underpriced, subsidies to tractor-hire services, the hidden cost of government extension activity to support a mechanical innovation, absence of tariffs on imported machinery, lack of tax on fuel for tractors, etc. In an economic analysis each of these distortions in price must be corrected.

The review of literature follows next. In the review, some representative studies from Asia, Africa and Latin America are examined. By contrasting the methodologies used in these studies one can determine which approaches are particularly useful for reaching policy conclusions. Suggestions for the redirection of research on farm mechanisation follow in Section V.

Short-Term (Static) Research

The review begins in the left-hand box of Table 1, short-term studies, and the first methodology listed there is cost-benefit analysis.

[6/] Eicher, et. al. [1970] and Thirsk [1972-a].

Cost-Benefit Analysis[7/]

Cost-benefit analysis, or budgeting, is the simplest approach to organising the data collected. Table 1 shows that it has been widely used, especially for a single farm, district or project, but also occasionally for a whole country.

Before embarking on the review it is necessary to explain the method and list some of the important variables. To simplify the discussion the changes in inputs and outputs will be considered that might follow the introduction of tractors into a village which previously used bullock-power.

Table 2 illustrates a cost-benefit budget. It is divided into losses on the left-hand side and gains on the right-hand side. Variables which can be measured in monetary terms appear at the top of the table; the social losses and gains are listed at the bottom.

Monetary Benefits. The first class of benefits comes from extra revenue following the change from bullock-power to tractors. Firstly, crop yields may increase due to improved timeliness and quality of cultivation. It is accepted dogma that higher yields occur when using tractors,

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[7/] Cost-benefit analysis is illustrated here with the "internal rate of return" or "yield" method. In this method one calculates the discount rate (internal rate of return) at which the future streams of monetary costs and benefits are equated. Projects are then accepted if their internal rates of return exceed the opportunity cost of capital. For general references see Prest and Turvey [1965], Little and Mirrlees [1969] and Mishan [1971]. For agricultural applications see Gittinger [1972].

Table 2. Village-Level Cost-Benefit Budget: An Example of a Change from Bullocks to Tractors

Losses[a]	$	Gains[a]	$
Revenue Lost		Extra Revenue	
		Yields Increase	$\Delta Q_1 . P_Q$
Custom Work (Bullocks)	$H . P_{HB}$	Crop Intensity Rises	$\Delta Q_2 . P_Q$
		Crop Mixture Changes	$\Delta Q_3 . P_Q$
		Acreage Increases	$\Delta A . Q/A . P_Q$
		Custom Work (Tractor)	$H . P_{HT}$
		Alternative Use of Bullock Land	$A_B . Q/A . P_Q$
Extra Costs		Costs Saved	
Fuel, Service, Reapirs	M_T	Bullocks' Concentrated Feed	$F . P_F$
Hired Labour	$\Delta L_H . P_L$	Hired Labour	$\Delta L_H . P_L$
		Maintenance of Bullock Equipment	M_B
Loss of Cash Income	ΔY_1	Gain in Cash Income	ΔY_2
Social Loss		Social Gain	
Polarization of Income Distribution		Increase in Leisure and Decrease in Drudgery	
Increase in Unemployment		Increase in Prestige of Some Individuals	
Polarization of Village Structure			

Key

ΔY_1	= Loss of Cash Income	L_H	= Hired Labour
ΔY_2	= Gain in Cash Income	F	= Bullock Feed
$Q_1 \ldots, Q_n$	= Outputs	P_Q	= Vector of Product Prices
A	= Acreage of Crops	P_L	= Wage Rate
M_T	= Tractor Running Costs	P_F	= Price of Bullock Feed
M_B	= Bullock-Equipment Running Costs	P_{HB}	= Price per Hour of Bullock Custom Work
A_B	= Bullock Land in Acres	P_{HT}	= Price per Hour of Tractor Custom Work

[a] The gains and losses of income (or "cash flows") occur over many years but are shown for one year in the table. Internal Rate of Return is calculated from:

$$\sum_{i=1}^{n} \frac{\Delta Y_{2i} - \Delta Y_{1i}}{(1+r)^i} - C = 0$$

where, $\Delta Y_{2i} - \Delta Y_{1i}$ = Change in cash flow in year i, C = Capital cost of project, n = Project life, r = internal rate of return.

but the evidence is generally inconclusive.[8/] Few researchers have attempted to quantify the effect of tractors on such important variables as time of planting. In a bullock-power study in Malawi, Gemmill [1971] found that this method of traction was no more timely than hand labour since neither system could operate before the first rains. Similarly, Kolawole [1972] showed that farmers in Western Nigeria often had to wait for the government tractor-hire service and this led to delayed planting. More specific studies of the effect of using tractors on queuing of farm operations are needed.

A second potential source of extra revenue is increased cropping intensity. One of the main advantages of using tractors in the Indian Punjab comes from the abbreviated delay for cultivation between crops, so that double or triple cropping is facilitated. Such advantages of tractors are limited to regions with either a source of irrigation water (e.g., Punjab) or more than one rainy season (e.g., some parts of Uganda).

A third potential source of increased revenue is a shift to more labour-intensive crops which are of higher value (e.g., a change from maize to cotton cultivation).

The preceding changes in output and revenue have been due to increases in the intensity of land use, but the possibility exists of an individual increasing his cropped area following mechanisation. The duration of fallowing may be reduced, previously uncultivated land may be used, or the mechanised farmer may open new land or take on land from his neighbors. The ease with which an individual obtains more land depends on the availability of idle land and on local institutions, such as the systems of credit

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[8/] For evidence from South Asia see Yudelman [1971] and for evidence from Africa see Kline, et. al. [1969].

and land tenure.[9]

A less obvious gain from the change to tractors comes from the additional output of land previously used for grazing by bullocks. In areas where the animals utilise waste-ground the gain may be minimal, whereas in an intensive agriculture, such as that in Pakistan, the gain may be significant [Bose and Clark, 1969].

Finally, the tractor-owner may increase his revenue through custom work for other farmers and thereby spread his overhead costs over a larger acreage. An example of this is the system of tractor-hire in some parts of Bangladesh [Esmay and Faidley, 1972].

The second class of benefits comes from costs saved. The most important, and most troublesome to assess, is a saving of hired labour. Following tractor cultivation a change in the pattern of labour requirements is often observed. For example, in their excellent study of the Indian Punjab, Singh and Day [1972] showed that more casual labor was hired following tractor cultivation due to an increased demand during the nonmechanised harvesting season. However, they also showed that less labour was required than previously during other seasons. It is important for the researcher to observe seasonal patterns of labour inputs and to distinguish between family and and hired labour.[10]

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[9] The literature is full of examples of tenant eviction by landlords following mechanisation (e.g., Mississippi Delta [Day, 1967], Turkey [Hirsh, 1970], Punjab [Singh and Day, 1972], and Ethiopia [Ellis, 1972]). However, many African systems of tenure would not, in their present form, allow such large-scale structural adjustment.

[10] It is confusing to discuss or measure demand for labour as "man days of labour per year", since the total demand for hired labour might be concentrated in one month and then result in eleven months of "unemployment".

Other savings may include the repair costs of the bullock equipment and the cost of concentrated feed for the animals. It is often said that bullocks are in their worst physical condition at the beginning of the rainy season, when they are most needed for work. In Malawi the annual mortality rate of the animals approached 20 percent [Gemmill, 1971]. This would be an additional saving if tractors were used. The benefits are now completely specified and we turn to the cost side of our budget which is more simple to estimate.

Monetary Costs. There may be a small loss of revenue which previously came from the hire of bullocks for tasks such as carting. The main components of cost are, however, the extra costs of the fuel, service and repairs for the new equipment. Service and repair costs are likely to be higher in less developed countries than in comparable circumstances in the U.S.A. [Kline, et. al., 1969]. Another important component under extra costs is the cost of any additional hired labour: the complexity of this calculation has already been discussed under benefits.

The financial appraisal is completed by separately totaling monetary benefits and costs. If depreciation charges have been included, one can directly compare the two sums for an "average year". A more accurate method is to produce a series of benefits and costs through time and follow a discounting procedure. If the monetary gains exceed the losses, the change to tractors may be considered profitable to an individual. However, such private profitability does not, of course, guarantee that the change to tractors will occur. There are other perceived attributes of mechanisation which may attract or repel individuals and villages. Some of these attributes are listed under social losses and gains at the bottom of

Table 2.[11]

Social Benefits and Costs. One social benefit of increased mechanisation in the village is an increase in leisure or a reduction in the "drudgery" of hard manual work. Similarly, if mechanisation increases the return per hour of labour, we may expect the substitution-effect to lead to more work and the income-effect to lead to more leisure. The net effect will probably be less work than previously.[12] A second benefit of this type is a gain in the prestige and authority of the individual who mechanises. Just as the tower-silo was a sign of an aspiring farmer in Britain in the 1960's [Dalton, 1967], so is the tractor in the Punjab [Frankel, 1969], and the ox team in Malawi [Gemmill, 1971]. Such investments are not easily hidden and create jealousy among farmers. Gemmill [1972] found that the main reasons for the spread of ox power were not economic but social, particularly important being a gain in prestige and ease of life. A further social aspect is the change in the general level of employment in the village, but this will be covered later in a more aggregate analysis.

On the loss side of the social account, the effects of a change in village norms and institutions are listed. One may expect a more extreme income distribution and a change in the pattern of village authority to follow mechanisation. Gotsch [1972] has discussed such changes with reference to the Punjab, as have Hinderik and Kiray [1970] with reference to Turkey.

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[11] What one person perceives as a gain may be a loss to another--the old externality problem.

[12] Winkelman [1972] also draws attention to the pace of work as a variable under the farmer's control. If returns to labour increase, the pace of work may increase rather than the hours of labour.

At this stage the village-level financial cost-benefit analysis is complete. The calculations (under the assumptions made) show whether the change in technology is profitable to the individual farmer and what social effects it may have on the village.

Economic Analysis. To convert from a financial to an economic analysis, it would be necessary to convert to their "shadow" levels those prices which do not reflect the true opportunity cost of resources. For example, if there is unemployment in the village the shadow price of labour may be zero, yet in the financial analysis an estimate of the wage-rate of hired labour may have been used. Frequently, the prices of tractors, fuel and products must be similarly adjusted. Once the shadow pricing is done, the costs and benefits may again be summed and, after discounting, the economic profitability of the change from bullocks to tractors can be assessed.

Review of Completed Cost-Benefit Studies. Most economic studies of farm mechanisation in developing countries (as can be seen by the sample in Table 1) have used this simple cost-benefit framework. Typically a single alternative to the present system has been discussed, such as bullocks versus tractors, tractors versus human labour or human labour versus bullocks.[13/]

In the bullocks versus tractors class of study fall works by Ellis [1972] and Green [1972] in Ethiopia, Chancellor [1970] in Thailand and Malaysia, Yudelman [1971] in Sri Lanka, Chopra [1972] in India and Lidman [1968] in Peru. The Ethiopian studies and that of Lidman in Peru will be further examined.

[13/] The authors have also found one study of multiple choice, that of rice mills in Indonesia, for which five alternative rice-milling technologies were specified [Timmer, 1972-a].

Green collected information for four case studies of mechanisation in different parts of Ethiopia, using secondary data supplemented by informal interviews with local people. His approach may be demonstrated by looking at one of the studies, that of Chilalo Awraja in the Central South of Ethiopia. An eight hectare farm was selected as representative of the district and budgets were drawn up of the costs and benefits of changing from the present bullock technology either to improved bullock power or to tractor-hire. The costs were those of providing a package of technology including improved seeds and fertilizer. Benefits were expected to come from higher yields and a larger crop acreage. From a mainly financial analysis Green concluded that the returns from a small project with improved bullock-power or tractor-hire were modest. However, the bullock option provided more employment and was therefore preferable to tractor-hire.

Green was the agricultural economist in an interdisciplinary research team which conducted a stock-taking survey of mechanisation in equational Africa.[14/] In consequence, the data he collected were not really tailored to the later analysis in which large assumptions had therefore to be made. Within these assumptions, Green adequately tested the financial (and to some extent economic) profitability of mechanisation in his four case study districts, but no national policy conclusions could be drawn.

Ellis' work in Ethiopia may be contrasted with that of Green. Instead of conducting four rapid case studies in different districts, he conducted one case study of bullock power versus tractor-hire in Ada District near Addis Ababa. Ellis spent approximately one year conducting small surveys of yields

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[14/] Kline, et. al. [1969].

and cultural practices on farms with and without tractors. He then drew up his cost benefit budgets using shadow prices to correct for an over-valued currency, duty free fuel and subsidized credit for tractors. Ellis concluded that both the financial and economic returns to mechanisation with tractors were low; yet tractor use was becoming more widespread despite this. He rationalised this paradox by observing that the landlords had better access to information, credit and other factors of production than their tenants. The landlords could obtain the advantages of the new seeds and fertilizer directly through evicting their tenants and mechanising, rather than having to wait for the tenants to adopt the new bio-chemical technology at less intensive levels. Ellis, like Green, showed that cost-benefit analysis may be useful in reaching policy conclusions about mechanisation for a single district. However, again like Green, the data he collected were probably not very reliable since his sample size was very small.

Lidman [1968] conducted an economic analysis in Peru similar to that of Ellis in Ethiopia, except that Lidman examined the economics of mechanisation in two contrasting districts. Tractors were introduced in Peru in significant numbers in the 1950's; consequently, Lidman had the advantage of a relatively stable situation with regard to technology for his analysis in the late 1960's. In the first valley, Jequetepeque, Lidman interviewed 7 farmers whose farms averaged 90 hectares. The main crop was rice and the economic question whether to use a combine. Lidman concluded that combines were both financially and economically profitable.

In the other valley of Mantaro, the median farm size was 7 hectares and the main crop was potatoes. The analysis revealed that mechanised potato planting was financially and economically profitable. Thus,

mechanisation in two valleys in Peru was shown to be desirable from both individual and societal viewpoints, but conclusions for the entire country cannot be drawn from the study of two valleys. It is also questionable whether it is sufficient to examine only the economics of mechanising one crop, such as the potato in Mantaro, when the power source, the tractor, is going to be used on all crops.

In the tractors versus human labour category come studies which include those by Van Wersch [1968] in Morocco, Lord [1963] in Tanzania, Baldwin [1957], Purvis [1968] and Kolawole [1972] in Nigeria and Dalton and Enikwaw [1971] in Ghana. The typical study in this class has been of a tractor-hire service which is either currently operating or is of recent demise. Studies of tractor-hire are a favourite among economists, because their records are easily available and the failure of tractor-hire has been common in many African countries.

Kolawole [1972] recently completed a study of the tractor-hire service in Western Nigeria. Initially he had proposed to analyse a cross-section of farmers at several different levels of mechanisation, but like many other lone economists he was forced to reduce the size of his study. He concluded that there was little financial advantage to the farmer from the service and that the service was also not financially viable. Costs of the service were high due to the usual causes of frequent breakdowns, shortage of operators, low hours of tractor-use per year, etc. Thus, again cost-benefit is shown to be a good framework for answering a simple question in one district. However, one may question the usefulness of studying one mechanisation option, such as tractor-hire scheme, when other options may be equally important.

In the bullock versus manual labor category are studies by Renaut in Ivory Coast [1966], Laurent in Nigeria [1968], Gemmill in Malawi [1971], and Weil [1970] and Peacock [1967] in Gambia. Gemmill made a comparative study in one region of Malawi of 132 farmers, half of whom used hand methods and half of whom used bullock-power. Using simple budgets and utilising labour information from separate surveys, he concluded that the private profitability of bullock-power was very low.[15/] However, bullocks were used by farmers for social gains such as a reduction in drudgery and a gain in prestige. It appeared that bullock-power in a country as densely populated as Malawi could not lead to increased crop acreage and hence was not important in development. The study did not, however, properly examine the possible revenue to be gained from carting by bullocks as cash-crop production increased.

The review now moves from the local and regional level to the country-wide level of analysis. An excellent comparison of the difference between financial and economic analysis is afforded by the analyses of Weitz-Hettelsater Engineers [1971] and Timmer [1972-a] on rice-milling in Indonesia. Weitz-Hettelsater Engineers reported at great length on the technical efficiency and financial costs and benefits of five alternative methods of milling rice for the whole of Indonesia. The options ranged from hand-pounding to a large bulk unit. The report recommended the purchase of equipment of the greatest capital intensity at a cost of $63.2 million and employing 7,300 people. Timmer conducted an economic analysis of rice-milling by reworking the data and using shadow prices. He concluded that,

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[15/] Because of the large number of drivers involved, the man days to cultivate an acre with a bullock team were the same as for hand labour.

of the five options, it would be most economically profitable to use the smallest power-mills. This would cost $12.5 million in investment and employ 14,700 people.

Timmer was fortunate in a number of respects. He had a good engineering analysis from which to begin his calculations. To provide similar data on a number of alternative mechanisation strategies for agricultural production in an entire country could be prohibitively expensive. Agricultural production has multiple products and a timeliness aspect which are not as important in rice-milling.

Both Bose and Clark [1969] and Kaneda [1969] have applied cost-benefit analysis to the question of tractors versus bullocks for the whole of Pakistan. Kaneda listed the data needed for such an analysis and commented on factor-price distortions in Pakistan, such as the low exchange rate, lack of import duties and subsidised product prices. However, he did not attempt to empirically test his hypothesis that tractor mechanisation was economically undesirable.

Bose and Clark, on the other hand, assumed that mechanisation would grow at 12 percent per annum, as recommended by Giles [1967-b], and listed the costs and benefits which this would entail. They assumed that farms of 25 acres or more would become mechanised. The key benefit in their calculation was the value of bullock-grazing-land, which could be cropped if bullocks were replaced by tractors. However, they concluded that the recommendation of 12 percent mechanisation per annum was not economically profitable to Pakistan.

The authors recommend Bose and Clark's analysis to anyone considering the use of cost-benefit to answer such a policy question. They also recommend

Timmer's economic analysis in Indonesia for researchers studying alternative technologies in processing. Two features of Bose and Clark's analysis which typify studies of mechanisation make it less authoritative than that of Timmer. The data used by Bose and Clark were all from secondary sources and hence were probably of low reliability. Furthermore, they tested the simple hypothesis of 12 percent annual rate of mechanisation and its effect in 1975 versus a continuation of the status quo. Other hypotheses would be equally interesting to test, such as the effect of improved bullock-power or a different rate of mechanisation.

Cross-Section Studies

It is apparent that cost-benefit studies tend to have a local focus. If one wishes to draw more general policy conclusions, it is logical to conduct a cross-sectional survey of a region, comparing mechanised and non-mechanised farms in the analysis.[16/] Cross-section studies include those by Donaldson and McInerney [1973] on the Pakistan Punjab, Johl [1970] and Rao [1972-b] on the Indian Punjab and Inukai [1970] on the Central Region of Thailand.

Donaldson and McInerney [1973] were interested in analysing the effects of several recent World Bank loans to Pakistan for tractors. They used a simple random survey of approximately 3.5 percent of the farmers who had been accepted for loans, of whom only half had actually received loans. Eighty-five percent of these farmers were located in the Pakistan Punjab. In all, 200

16/ Using chi-squared tests, analysis of variance or a multiple regression analysis with mechanisation as an explanatory variable.

farmers were interviewed concerning the 1966/1967 (before loan) and 1969/1970 (after loan) seasons, the enumerators relying on the farmers' recall of what happened in those years. Unfortunately, the nonmechanised control group had mechanised to a large extent without loans so farm management data generated by the local universities were used for additional comparisons.

Donaldson and McInerney concluded that farm size had grown by an average of 240 percent on farms which had become mechanised. Twenty-two percent of the increase came from land previously uncultivated, 42 percent from land previously rented out, 24 percent from land newly rented in and 12 percent from land newly purchased. Therefore, the main effects of mechanisation had been a gain in income for the adopter and substantial tenant displacement, as landlords tried to secure economies of scale for their equipment. While the method of recall is questionable over such a long period (1966/1967 to 1969/1970 and survey in 1971), the tenant displacement was so extreme that it must be taken seriously.

Donaldson and McInerney used primary data for their analysis, but most researchers conducting cross-section studies of mechanisation have used secondary data.[17/] Studies by Rao [1972] and Inukai [1970] demonstrate the use of such data. The study of Rao [1972-b] is typical of Indian research in farm mechanisation. The methodology has almost universally been multiple regression analysis of some rather general data from previously completed farm management surveys. An example of this generality in Rao's study was the treatment of labour in terms of man hours per year, when seasonal differences in demand were likely to be extreme. Rao used mechanisation as one

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[17/] i.e., data not collected to specifically test the present hypotheses.

explanatory variable and crop intensity, yield, output and employment as the dependent variables in successive analyses. He found no relationship between tractors and employment or cropped area, but tractors seemed to increase output. His lack of relationships may be as much a function of a poor data base as of the lack of such interrelations. Multiple regressions are easy to complete, but, unless skillfully applied and based on reliable data, they yield little information for policy makers.

Inukai [1970] compared the use of buffaloes and tractor-hire in Thailand. Using cross-sectional data from 21 provinces in the Central Region, he showed that rice yields were higher where mechanisation had occurred.[18/] He explained this yield-effect through the deeper ploughing and greater timeliness of tractors, but did not fully substantiate these claims. He also concluded that tractors allowed ploughing to occur before the pre-monsoon rains and, as a result, labour was released for use in transplanting rather than broadcasting the rice. The transplanted rice gave higher yields. Thus, selective mechanisation (tractor ploughing) was complementary with other new technology (transplanting rice).

Inukai did not discuss costs or benefits, either private or social, at any point in his paper. His whole analysis was more descriptive than analytic. For example, he did not distinguish between different classes of labour such as family, permanently hired or casual; nor did he discuss the social consequences of mechanisation. To draw policy conclusions for Thailand, more rigorous and representative studies are needed.

[18/] Not that mechanisation led to higher yields.

Linear Programming (LP)

A good way to analyse the impact of new technology on a farm or homogeneous district is through linear programming. It is widely available on computers, simple in concept and provides a framework which can "direct" the collection of relevant data. For a farm study, it finds that mixture of activities which maximises income (or some other single criterion) subject to constraints such as the supply of labour, classes of land and rotational limitations. To observe the effect of different technologies, one simply runs the program with each technological mix in turn and observes farm income and labour utilisation.

Although LP has been used in regional models (e.g., Vaurs [1971] in the Ivory Coast, Panagides and Ferreira [1971] in Brazil), the method is most realistic when used to study a single farm.[19/] Examples of farm studies including mechanisation through LP are those by Clayton [1965] in Kenya and Ahmad [1972] in Pakistan. We will discuss Ahmad's study, as it is the most polished of these and has been extended by Gotsch [1973-a].

In his dissertation, Ahmad first used secondary data to examine trends in mechanisation in Pakistan. He then analysed a cross-section survey of 50 farmers drawn from three districts in the Punjab State of Pakistan. Nineteen of the farmers owned tractors, 19 used bullocks and 12 used tractor-hire services. The sample was not random, but a tractor-user and bullock-user were selected from the same village on the same soil type where possible. Input-output relationships for a linear programming model of a typical 50-acre farm in the wheat-cotton area were developed from the

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[19/] Because of aggregation bias at the regional level.

survey. Later 25- and 75-acre farms were also considered using the same coefficients.

With his model Ahmad showed that the incentive to mechanise was very great, but that the return to mechanisation depended largely on the farm having a tubewell. The financial rate of return to tractor ownership was only 3 percent without a tubewell, but with one it was 46 percent. The key to the 46 percent return was that water allowed greater cropping intensity and mechanisation eased the consequent increase in labour demand. Even when all factor-price distortions were removed, mechanisation was highly profitable to a farmer who had a tubewell.

Gotsch [1973] extended Ahmad's analysis to consider the reasons why tenant eviction was occurring so rapidly. He found that, although both landlord and tenant could gain through the tenant's mechanisation since rental was proportional to output, by evicting some of his tenants the landlord could capture even more of the benefits of mechanisation for himself.

Ahmad's survey showed that farmers who owned tractors were increasing crop intensity from the 144 percent of bullock users to 168 percent. But in the LP model crop intensity was pushed to its maximum level of 187 percent. Similarly, the model gave a crop mixture somewhat different from that in use on tractor farms in the survey. Either Ahmad's model gave some equilibrium situation to which a farmer was moving over a number of years, or the farmer's subjective constraints were not completely incorporated in the model. Ahmad, himself, chose the former explanation. He said, "The tractor farmers in the wheat-cotton area have not yet achieved the double cropping of which they are capable because most of the farmers have not yet accepted the 'unconventional' crop rotation of sowing wheat after cotton."

Such problems of interpretation arise whenever LP is used to make projections since it is a static method of analysis.

The limitations and possibilities of LP are well known. As a framework for studying the impact of mechanisation on individual farms, it has great educative value; it is probably the best tool available for short-term micro-analysis. Certain variants of LP can be used where the assumptions of LP are invalidated, but the cost of such methodologies tends to be high.[20/]

General Equilibrium

Thirsk [1972-a,b,c] in Colombia and Sanders [1973] in Brazil have attempted to examine the factors influencing the rate of mechanisation for a whole country, using aggregate data. These are "general equilibrium" studies because they begin by assuming that a country's factor and product markets are at a static equilibrium. They then attempt to show what equilibrium would exist under alternative factor and product prices. A discussion of Thirsk's study follows.

Thirsk was interested in discovering whether the Colombian Government's policy of providing credit for mechanisation at half the market rate of interest had increased or decreased GNP and employment, and whether the benefits of mechanisation had accrued to (the owners of) land, labour or capital. Using data from a variety of sources, including a national farm management survey and the National Accounts, he estimated the elasticity of substitution between labour and capital in agriculture as approximately

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[20/] e.g., indivisibility assumption--mixed integer programming; deterministic yields and prices--quadratic programming; fixed returns to scale--separable programming.

1.4, a figure similar to that in other countries. He then built a small simultaneous equations model of Colombian agriculture, concluding that the subsidisation of mechanisation had lowered GNP, favoured the capital-owning segment of society and resulted in lower agricultural employment.

Thirsk's work was analytically very elegant and did show the effect of one government policy. Such aggregate analysis would be a useful complement to micro-studies in moving from short-term into medium-term analysis. However, as Thirsk suggested, institutional questions such as land reform may be of much greater importance in Colombia's development than the question of whether to subsidise mechanisation. The analysis did not indicate what "should be done next" with respect to policies for selectively mechanising agriculture.

Medium-Term (Dynamic) Research

Medium-term studies address the question of what policy-decisions should be made concerning variables that indirectly affect farm mechanisation, e.g., minimum wage laws, product price levels, and domestic machinery manufacture. Medium-term research is either dynamic in conception--making projections under different policy-mixtures--or is concerned with measuring the effect of indirect variables on mechanisation.[21/] This section in Table 1 has been divided into three methodologies: budgeting, programming and simulation.

[21/] By contrast short-term studies are of directly operating variables in a static framework.

Budgeting

Budgeting in this context is similar to the cost-benefit analysis used for short-term studies, but with a longer time horizon and a focus on outcomes rather than on economic evaluation. Examples of studies using this procedure are the projections concerning new technology in Pakistan by Johnston, Cownie and Duff [1970], projections of the impact of mechanisation in the Indian Punjab and Maharashtra by Singh and Billings [1971], and the study of alternative farm mechanisation strategies in Pakistan in relation to domestic machinery manufacture and employment by Johnston and Kilby [1972].

Johnston, Cownie and Duff [1970] made projections for agriculture in Pakistan to 1985 under six different sets of input assumptions, which included three different rates of mechanisation. They stated that "even though the figures which emerge from this exploratory exercise are very rough, they shed light on some important questions of economic policy that would be difficult to evaluate without an assessment of the potential impact of the seed-fertiliser revolution." They drew no equivocal conclusions, but emphasised that tractor mechanisation might lead to increased output at such a rate that surplus production would have to be exported. They also believed that rapid mechanisation would adversely affect employment and income-distribution. Throughout the paper they emphasised the need for better technical information for making such projections.

Singh and Billings [1971] made projections to 1983-84 for the Punjab and Maharashtra of India, assuming present trends to continue for technology, crop mixture and population growth. They concluded that the demand for farm

labour would rise slightly in Punjab, but very little in Maharashtra, since that state has a more arid climate and less potential for irrigation. Consequently rural unemployment would increase in both states due to population growth and this would be particularly severe in Maharashtra.

The work of Singh and Billings has been widely quoted and provides a benchmark for policy debate. However, the employment projections rest on approximate assumptions for crop mixtures, new technology and labour demand. Singh and Billings considered one rate of mechanisation, while a number of alternative projections might have been made under different assumptions for comparative purposes. However, their projection of increased unemployment in Punjab in 1983-84 agrees with that of Singh and Day [1972] for 1980 (as shall be seen in a later section).

Johnston and Kilby [1972] projected the economic costs and benefits of local manufacture of three alternative machinery packages for Pakistan: 1) tractors and combines; 2) intermediate set centred on the power-tiller; and 3) improved bullock technology with a stationary thresher. They concluded that the intermediate set with power-tiller was both technically and economically inferior to either of the other alternatives. Of the two remaining options, manufacture of bullock technology was preferable since it would provide more employment than manufacture of large-scale machinery, a higher GNP and would economise on foreign exchange. This is the only empirical study of this question for any country. Similar studies in other countries could raise the level of the debate on whether farm machinery should be manufactured domestically.[22/]

[22/] It is interesting to note that Pakistan recently signed a contract with Massey Ferguson for the domestic manufacture of 4,000 tractors per year.

Programming

Under this heading come programming studies which have a dynamic component and hence make projections through time. Recursive linear programming has been used by Singh and Day [1972] to make projections for the Indian Punjab and by Singh and Ahn [1972] to analyse what would have happened in one part of Southern Brazil under alternative policy mixtures in 1960-1970. The method consists essentially of a series of annual linear programs, the coefficients of one year's optimising routine being dependent on the previous year's results. The method is really suited to analysing changes on a single farm, and, in this respect, is similar to linear programming. Thus, Singh and Day treated the Pakistan Punjab as if it were one large aggregate farm and Singh and Ahn treated Southern Brazil as if it were an aggregate of three farms of different sizes.

Before commencing their analysis, Singh and Day, in collaboration with Johl, collected an immense volume of secondary data [Singh, Day and Johl, 1968]. Using thesedata in their model, they simulated the impact of new technology (including mechanisation) for the years 1952-1965. Using this model, they then made projections to 1980 and demonstrated that the new technology increased the seasonality of labour requirements and caused a bottleneck at harvesting. Although the initial effect of the better varieties, fertilizer and irrigation had been an increase in employment, the absolute demand for labour was projected to decline 10 percent between 1970 and 1980 because of mechanisation, resulting in a labour surplus. By parametric variation for some years, they demonstrated that changes in wage and interest

rates would slow down or speed up the rate of mechanisation only slightly.[23/]

Singh and Ahn [1972] used a similar methodology in Southern Brazil except that the model was of three farm sizes and had a technology matrix with fewer alternatives specified. Historical runs for 1960-1970 showed that, unlike the Pakistan Punjab, the rate of mechanisation was very sensitive in Southern Brazil to interest rate, i.e., by removing its system of subsidised credit, which results in low nominal and negative real rates of interest,[24/] the government could have slowed down the pace of mechanisation.

Recursive linear programming has great appeal as a framework for making projections for individual farms through time. It was used very effectively in the Punjab study to show the interaction of new technology with labour demand and supply. Its capacity to make regional projections is questionable, however, since it treats a region as an aggregate of one or a small number of farm sizes. Although changes in the pattern of land ownership and farm size could be incorporated, the models are already both complex and expensive to run.[25/] In addition, to take a really comprehensive view, such as that in Figure 1, it would be too expensive to make recursive linear programming the main structural component. Recursive

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[23/] For the Pakistan Punjab, Gotsch [1973-a] similarly concluded that even if tractors were priced at their "shadow" level, mechanisation would still be profitable to the individual farmer.

[24/] Due to inflation.

[25/] It is often said of recursive linear programming that its weakest point is the arbitrary way in which it constrains the diffusion of a new innovation--the so-called flexibility constraints. However, other methods of incorporating diffusion into models are equally arbitrary. Research is needed which will predict the diffusion rate more rigorously than the research completed to date. (For a review, see Rogers [1971].)

linear programming is, therefore, probably an overly complex framework for analysing medium-term mechanisation questions.

Before leaving medium-term programming studies, some presently completed and projected work in Sierra Leone will be briefly mentioned. Dunstan Spencer [1973] recently completed a linear programming study of rice production in Sierra Leone based on his own farm management survey. During the next 3 years, Spencer and his colleagues will conduct surveys of farm production, rural-urban migration, rural nonfarm activities and rice processing in Sierra Leone for a comprehensive analysis of medium-term policy decisions (including mechanisation) in agriculture.[26/]

Simulation

Simulation does what an individual researcher does in making projections on the back of an envelope, only a million times faster. The greater speed allows a greater number of alternatives to be analysed and more complex relationships to be incorporated. Johnson, et. al. [1971] used this approach in analysing Nigerian agricultural policy, as have Rossmiller, et. al. [1972] in a similar analysis for South Korea. In the latter case, the projections to 1980 included some alternative levels of mechanisation. Simulation exercises might possibly be used in analysing the impact of new technology in developing countries, but, unless there is a very large volume of micro data available, such exercises are more useful in developing hypotheses for future testing than for actually analysing policy decisions.

[26/] This study will be undertaken by Spencer as part of the African Rural Employment Study which is described on the inside front cover of this publication.

Long-Term (Perspective) Research

In Table 1, long-term studies are divided into the historical and and the instrumental. "Historical" studies are backward-looking and not intended to give specific policy guidelines, while the main purpose of "instrumental" studies is to guide future long-term policy on farm mechanisation.

Historical Studies

Historical studies operate within the context of some philosophy of development, of which the two main schools are free-market capitalism and Marxism. These two philosophies are prescriptive only to the extent that capitalism advocates a policy of laissez faire and Marxism advocates direct involvement of the state in the production process. For farm mechanisation, the former policy means accepting the rate and type of mechanisation which "naturally" evolves and the latter policy means the enforcement of only "socially desirable" rates and types of mechanisation. The neoclassical or free market model concentrates on the importance of the relative prices of labour and capital in determining the rate and pattern of technological change. By contrast the Marxian model concentrates on "...the importance of structural change and accumulation, and how production and technical change lead to both increased quantities and new patterns and relations of production..." [Roberts, 1972].

The findings of some historical studies of mechanisation, in countries which follow each of these two philosophies, are examined below. These studies show that the philosophy of development adopted by a country does

affect the rate of agricultural mechanisation, even though different countries professing the same philosophy may decide on different strategies. No medium or short-term planning will be of any consequence unless the decisions made in those time horizons are consistent with a country's long-term goals.

Capitalist Agriculture and Mechanisation. In Western Europe one of the first important innovations in farm mechanisation was the use of the heavy plough and ox team. Although oxen are still used in some parts of Central Europe, the horse was first used as a draft animal in the 9th or 10th century and became widespread in the 12th and 13th centuries [White, 1964]. The use of the horse was facilitated by the invention of harness and horseshoes and by the growing of oats for forage. Thereafter, there was no change in farm motive-power for seven centuries until the tractor was invented in modern times.

The increased output of food which was demanded by the industrial revolution in Europe was the result of agricultural innovations, such as the three and four course systems of rotation, in an earlier period. This agricultural revolution in England in the 18th century, it is now believed, did not cause an absolute but only a relative decline in the total population engaged in agriculture.27/

The development of the tractor and most modern mechanical technology in agriculture occurred in Western Europe and the U.S.A. Hayami and Ruttan [1971] argue that the high price of labour relative to capital in the

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27/See, for example, Timmer [1969] on the influence of the new husbandry on the demand for labour.

1910-1940 period induced rapid mechanical innovation for U.S. agriculture. Certainly mechanisation was highly profitable in that period, as has been well demonstrated by Day [1967] in a recursive linear programming model of sharecropper displacement in the Mississippi Delta.

By contrast the diffusion of tractors in Western Europe in the same period was much slower, due partly to lower wages and also to a cropping pattern with less seasonal labour bottlenecks [Jasny, 1935]. In Britain, tractors were first adopted for heavy work, without displacing horses, and only after further increases in relative wage levels was the pattern of agriculture adjusted to full mechanisation [Whetham, 1970].

Communist Agriculture and Mechanisation. Countries which have followed (e.g., Russia) or are following (e.g., China, Cuba) some interpretation of the Marxist pattern of development present a very interesting contrast in their attitude to agricultural mechanisation. Marx did not have a well-developed theory of agricultural development. He believed that capital-intensive development would occur simultaneously in the rural and urban sectors before the advent of the revolution. Miller puts it this way.

> In agriculture as in industry, he (Marx) saw as an inevitable tendency the crowding-out of the small-scale, independent producer. Those peasants who remained on the land would be reduced to the status of rural proletarians, not essentially different in life-style and attitude from their urban brethren of the same class. By the time capitalist socioeconomic conditions had been driven to the point of revolution by their own inner dynamic, he predicted, the peasant question would have ceased to exist. [Miller, 1970]

It was left to Karl Kautsky [1900] to present a "Marxian" model in which rural capitalisation lagged behind its urban counterpart. Kautsky believed that:

> ...capitalist experience had shown that the potential of mechanized farming could be realised only in large-scale operations. However, only the socialist state, the epitome of economic concentration and rationalisation, would be able to apply the lessons consistently. [Miller, 1970]

Russian experience after the revolution was that the peasantry stubbornly refused to be socialised. The New Economic Policy (NEP) of 1922-1925 relied on monetary incentives to increase farm output rather than on a process of socialisation. Thereafter the policy was reversed--agriculture was forcibly reorganised into cooperative and collective farms and a Machine Tractor Station (MTS) system was established whereby tractors were widely introduced into agriculture through centralised services rather than through individual ownership. In Russia the tractor was a means of socialising agriculture rather than a method of increasing output. As Miller puts it, "Lenin and the Bolshevik leaders quite genuinely believed in the socialising power of the tractor, and, indeed, were counting on it to do much of the necessary transformational work in the village." [Miller, 1970]

As a result, Russian agriculture became "overmechanised" by the standards of neoclassical economic theory. By 1935 Jasny reported that many tractors were used in Russia <u>despite</u> the extremely low wage level. "The particular conditions of the 'socialisation' of agriculture are driving mechanisation beyond the limit warranted by natural and economic conditions." [Jasny, 1935]

Turning to China, the little information available suggests a concentration on small-scale labour-intensive agriculture rather than a highly mechanised system. Although in 1955 Mao produced a "Twenty-five Year Plan" for the mechanisation of agriculture, Wheelright and McFarlane [1970] report that mechanisation so far is limited to pumps for irrigation, small mechanical

ploughs and semi-mechanised rice transplanters, all of which can be locally produced. It appears that the development of communes in China has been sufficient to bring about agrarian socialism without resorting to a Russian-style mechanisation strategy. In the Russian case a high degree of mechanisation in agriculture was induced by importing U.S. technology and machines, but this option has not been available to China since her break with Russia in 1960.

Next there is the Cuban case. According to Abercrombie [1972], Cuba has more tractors per hectare than any other Latin American country. The reasons for this high degree of mechanisation appear more economic than doctrinaire. After a premature policy of "industry first" and reliance on a market type of agriculture, Cuba returned to a policy of development based on agriculture in the mid-1960's [Mesa-Lago, 1971]. Since sugar is the most important agricultural and export product in Cuba, the government has greatly increased the acreage under sugar in the last few years. The result has been a shortage of labour at harvest-time. The recent much publicised system of "voluntary labor," in which workers from the towns harvest sugar-cane for no remuneration, is estimated by Mesa-Lago [1969] to have increased the labour supply to the whole economy by about 10 percent, but in the long-term mechanised harvesting with Russian equipment is being adopted as the solution to labour shortages.

Instrumental Studies

Finally there are long-term studies which have proposed that a society change certain institutions in order to mitigate some of the ill effects

of inevitable mechanisation. Schmitz and Sekler [1970] examined the effect of the introduction of the tomato harvester in California. Using the compensation principle of welfare economices as a framework, they showed that even if the displaced labourers had been compensated for 5 years by the employers at their previous wage level, the harvester would still have been financially profitable. Schmitz and Seckler concluded that a new institution was needed to compensate the losers in such technological change, when the losers were not organised to negotiate their own compensation.[28/] Although there are many practical difficulties in organising such an institution in the U.S.A.,[29/] new technology is not neutral in its impact and the winners should pay the losers in some manner outside the normal system of taxation.[30/]

Gotsch [1972] compared the impact of mechanisation in Pakistan with that in Bangladesh. He concluded that the impact in Pakistan had been less equitable since the distribution of land, capital and power in the two societies differed considerably. Divisible tractor-hire in Bangladesh was contrasted with indivisible private ownership in Pakistan. Gotsch concluded that economic studies needed to be integrated into a political and social framework. He said,

> too few studies confront explicitly the feasibility of their proposals in the context of a particular system... Research that would relate quantitative changes in system parameters to qualitative changes in the system's behaviour is badly needed. [Gotsch, 1972]

[28/] i.e., not unionised.

[29/] See Dalrymple [1971].

[30/] Suggestions that normal taxation will result in adequate income redistribution (e.g., Chopra, 1972) are very unrealistic, especially in developing countries.

The authors hope that the general equilibrium framework, developed in Figures 1 and 2 of this paper, may be a further step in making operational the kind of institutional analysis which Gotsch developed and which has also been discussed in the American context by Schmidt [1972]. Such analysis is essential if the policy-maker wants to predict and mitigate the deleterious side effects of rapid technological change in agriculture.

V. SUMMARY AND NEEDED REDIRECTION IN ECONOMIC RESEARCH ON FARM MECHANISATION

Summary

Decisions to be made by government on mechanisation may conveniently be divided into short, medium and long-term horizons. Short-term policies are those which directly affect the rate and type of mechanisation (e.g., the choice of mechanisation options in government agricultural projects). Medium-term policies are those which affect mechanisation more indirectly and are less immediate in their impact (e.g., minimum wage legislation). Long-term policies are the continuation of short and medium-term policies over a period of several decades.

Researchers have concentrated on short and long-term policy questions, while the medium term has generally been neglected. For example, short-term research has provided snapshots of farm mechanisation in single districts and long-term research has developed theories about capital/labour substitution drawing on the experience of western countries, but medium-term research has been limited to a few tenuous attempts to predict the effects of mechanisation within a time horizon of from 5 to 15 years.

From a review of the literature, it is apparent that many economic researchers have drawn unjustified regional and national conclusions from

studies of mechanisation in limited geographical areas. Short-term studies of mechanisation have often been the products of lone economists who had the resources neither to collect representative data nor to analyse a range of alternative mechanical technologies. When secondary data have been used (e.g., the results of government sample surveys of agriculture), it has not been possible to separate the effects of mechanisation from those of other influences. Sharply divergent policy prescriptions have resulted from such research.

Economic studies of mechanisation for medium-term policy-making face conceptual and methodological problems in dealing with changes in institutions as well as in economic aggregates through time. Medium-term studies have helped to specify the alternative policies available, but have been unable to give definitive regional or country-wide policy guidance on mechanisation. A conceptual framework is presented in section II of this paper, which attempts to clarify the variables at play and their interactions in a medium-term context.

Long-term studies of mechanisation are divided into the "historical" and the "instrumental". Historical studies are backward-looking and not intended to give specific policy guidelines, hence of little importance to developing countries. Instrumental studies delineate long-term goals and suggest institutional changes which may facilitate the achievement of these goals--while few in number, such studies are of great importance in placing questions of mechanisation-policy in a socio-political context.

No conclusions have been drawn in the paper, but certain redirections which will make research more relevant to policy-making are listed below.

Needed Redirection in Economic Research on Farm Mechanisation

1. Gearing Research to Short, Medium and Long-Term Policy Questions

Our review of the literature has indicated that a large percentage of economic studies of farm mechanisation have not clearly specified the policy questions being pursued. Research design should include an explicit statement of the policy questions to which the research is directed, in order that the research can be tailored to meet specific short, medium or long-term policy questions.

2. Single Versus Multiple Mechanisation Options

Although studies of single mechanisation options (e.g., tractor hire schemes) are relatively easy to carry out, they are of limited value to policy makers who are faced with choosing among alternative mechanisation options. Research in the short and medium-term should emphasise the trade-offs inherent in alternative mechanisation options for specifc commodities, geographical areas, etc.

3. Data Needs

The literature review has shown that much of the secondary data available through government farm surveys are inadequate for policy analysis on mechanisation. Such surveys give background information (e.g., sizes of holdings, man/land ratios, implements in use, etc.), but cannot show the changes in output, income distribution and the demand for labour which follows mechanisation. To estimate these variables, year-long micro-level surveys of farm production and rural nonfarm activities are required.

4. Short-Term Research

Short-term research will continue to be an important service to policy makers, since urgent decisions on mechanisation are taken every day. Single economists, or a small group of economists, carrying out short-term studies should take into account the following:

a. Financial versus economic analysis. Much of the confusion between engineers and economists (and frequently among economists) on mechanisation stems from a lack of clear understanding that the (financial) profitability of mechanisation to an individual or project may differ from its (economic) profitability to society. The economic profitability is calculated using prices which reflect the true scarcity of resources, i.e., in the economic analysis factor price distortions, such as an overvalued currency exchange rate, are corrected. Both financial and economic analyses are essential for sound policy analysis. Economists have often accounted for a limited number of factor price distortions without recognising that other such distortions may be counterbalancing. Research on factor price distortions should be as comprehensive as possible.

b. Limited conclusions. The review of literature has clearly shown that many short-term studies have "masqueraded" as medium-term studies (i.e., they have drawn very general conclusions for whole regions or countries when they are only relevant to specific locations and the present time). It would be judicious for short-term researchers to recognise the limitations of their data and analysis.

c. Analytical techniques. Cost-benefit analysis has proved useful at the local, regional and national levels. However, linear programming is a preferable tool for analysing mechanisation on individual farms, since a number of alternatives can be intensively studied with computational ease. Although multiple regression analysis of cross-section data is potentially useful, it has been of limited use to policy-makers as a result of inadequate data and of the bias resulting from the omission of relevant variables. For example, the total increase in output in a region may wrongly be attributed to increasing mechanisation when increased irrigation, which was not measured and not included in the regression analysis, may have been equally important.

5. Medium-Term Research

Economic research on mechanisation per se is too narrow to guide policy makers in the medium-term time horizon. Consequently, research on mechanisation should be incorporated into a broader study of agricultural production systems which analyses the interactions between packages of technology and the labour, input (capital) and product markets. Such a study implies a team approach which includes economists, engineers, sociologists and technical experts (agronomists, soils specialists, etc.). Figures 1 and 2 have outlined the necessary components of such a study. Other important issues in carrying out medium-term research include:

a. Methodological problems. Operational methods for tracing the impact of mechanisation on income, employment and income-distribution in the medium term are still in the formative stage. There is a need for further conceptual work, such as that of

Gotsch [1972] and Thirsk [1972-a]. A further need is for more research on the aggregation bias which occurs in the prediction of aggregate variables from representative micro-data. Research is needed on both the sources and methods of elimination of this bias.[31/]

b. Analytical techniques. Budgeting is a standard and useful technique for elementary appraisal of a limited number of mechanisation policies, but when many alternatives are being considered computer simulation is much more efficient. Unfortunately, most developing countries do not have sufficient and reliable micro-data for simulation to be useful in policy analysis at the present time. Although recursive linear programming (RLP) is not endorsed by many scholars, it has great appeal as a framework for making projections for individual farms through time. However, we are skeptical about its capabilities in aggregate analysis of alternative mechanisation options. Clearly there is a need for more conceptual work on analytical techniques for the medium term.

6. Selective Mechanisation

Mechanisation is so country and commodity specific that it is impossible to give general policy recommendations. It is also fruitless to discuss "a national mechanisation strategy to minimise labour displacement" or "policies to maximise agricultural development while minimising social conflict.[32/] Researchers should recognise that there are trade-offs

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[31/] Some useful research in this area has already been completed by Day [1963], Miller [1966] and Buckwell and Hazell [1972].

[32/] Shaw [1970].

between the goals of agricultural development on the one hand, and avoidance of social conflict and labour displacement on the other hand. The most acceptable policy on mechanisation will necessarily be a compromise between alternative goals. One type of policy which embodies such a compromise is concerned with selective mechanisation to overcome seasonal labour bottlenecks. Once these bottlenecks have been identified, engineers and agronomists may direct their research to breaking them and the economists may devise policies which will encourage the selective mechanisation of such bottlenecks, without leading to mechanisation of all farm operations.

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