

Chapter 1

INTRODUCTION TO THE RESEARCH

1.1 Introduction

The topic of the research for this dissertation is introduced in this chapter. The problem of the choice between alternative techniques of land preparation is discussed in section 1.2 in the context of farmers in the Luwu district of South Sulawesi, Indonesia. The objectives of the study are outlined in section 1.3, while associated hypotheses are presented in section 1.4. Quadratic programming models of a small number of case study farms were developed and mean-variance (E,V) efficiency analysis conducted. This is described in section 1.5, while a brief outline of the dissertation is provided in section 1.6.

1.2 The Problem

The advantages and disadvantages of tractor use in developing countries have been the focus of much debate in the literature (see Chapter 2). Potential advantages include increased cropping intensity and yields, while the displacement of labour is frequently cited as a disadvantage. However, the substitution of tractors for human labourers may be hailed as beneficial in areas of apparent labour shortage. This was the case in the Indonesian province of South Sulawesi. The first tractor feasibility study in the province was conducted by Parusengi (1972). The conclusion was that small tractors should be introduced to relieve a labour shortage. This finding was confirmed in subsequent studies (Directorate of Food Crops 1975, Agricultural Extension Service and Association of Devotees of Agricultural Mechanization in Indonesia 1976, Gadjah Mada University 1976, Directorate for Technical Agriculture 1979).

In 1976, the Luwu Area and Transmigration Development Project was initiated with finance from the United States Agency for International Development (USAID) and the Government of Indonesia. One of the components of the project was the establishment of a tractor hire service for Luwu farmers. Subsidised credit has also been made available from government sources for the purchase of tractors.

A survey carried out in another district of South Sulawesi revealed that '... tractor ownership was not economically viable because of breakdowns and a shorter than expected working life' (Hafsah and Bernstein 1983, p. 85). Associated studies found that '... mechanization of land preparation had no impact on cropping intensity in irrigated areas ...' Moreover, '... no impact on yield was detected ...' (Maamun et al. 1983, p. 177). In 1982, a research project was undertaken to assess the comparative performance of hand-tractors, four-wheeled mini-tractors and animal power in Luwu (Luwu Area and Transmigration Development Project and International Rice Research Institute 1983). Hand-tractors were found to be superior to mini-tractors because of their lower operating costs and greater mobility. No yield or cropping intensity effects were identified.

All of the studies mentioned above focussed on the consequences of tractor use or purchase. However, there have been no studies in Luwu concerning farmers' choice-of-technique decisions or of the potential influence on those decisions of such factors as risk perceptions, tractor hire cost, labour availability and cash flow. Although tractors were initially introduced because of apparent labour shortages, it may be the case that labour availability is not a significant factor in determining the decisions of Luwu farmers. The current study addresses such issues. It is hoped that the results of this study may be of interest to policy-makers in South Sulawesi, and specifically in the Luwu district, by indicating the conditions under which tractor use is likely to be optimal for small rice farmers. In more general terms, this study is a contribution to existing knowledge concerning the economics of tractor use in developing countries.

1.3 Objectives of the Study

There are two main objectives for the present study. The first of these relates directly to the problem of technology choice outlined in section 1.2. The intention is to examine the issue of tractor adoption from the viewpoint of the individual farmer. Conclusions may then be drawn regarding the optimal levels of animal and tractor use on the sample farms, given the farmers' expectations and risk attitudes. A full investigation of both private and social benefits and costs of machines versus animals is beyond the scope of this study. However, the results of sensitivity analyses suggest implications for the wider population.

The methodological objective associated with this study is to consider the usefulness of quadratic risk programming in the context of decision-making on small farms. The appropriateness of variance as a measure of risk, and of mean and variance as the sole components in 'utility' functions, is discussed in section 3.4.1. Practical difficulties in the elicitation of farmers' subjective beliefs and risk attitudes are outlined in section 4.4. In Chapter 6, the results generated by quadratic programming are compared with those of risk-neutral linear programming models. Conclusions are then drawn on the importance of risk and risk attitude in determining the technology choices of the sample farmers.

1.4 Hypotheses

The first objective outlined in section 1.3 is formally investigated in Hypothesis 1.

Hypothesis 1. At current prices and resource endowments, the use of tractors for the preparation of rice lands for selected farmers in Luwu results in the same maximum expected net value of farm-household production as that obtained if draught animals are used.

This hypothesis is assessed with reference to the risk-neutral linear programming models described in section 5.2. In view of the small sample size used in this study, the hypothesis cannot be tested statistically. Rather, the conditions under which this hypothesis is rejected or not rejected are determined for each sample farmer, as explained in section 6.4.

The effect of 'risk' (defined in terms of variance) on the optimal levels of tractor and animal use is investigated in Hypothesis 2.

Hypothesis 2. Over the range of degrees of risk aversion likely to exist, the levels of tractor and animal use which maximise mean-variance utility for the selected farmers are identical to the levels which maximise the expected net value of farm-household production.

It was not possible to elicit usable utility functions from the sample farmers (see section 4.4.5). Consequently, estimates of the most plausible range of the Pratt risk aversion coefficient are made with reference to previous research findings. Critical values of the Pratt coefficient, at which specific alternatives to the linear programming solution become optimal, are noted for each farmer. Hypothesis 2 is then assessed by comparing these critical values with the farmers' likely degree of risk aversion (see section 6.4).

1.5 Methods

The emphasis in this study is on optimal technological combinations for individual farmers. Linear programming is a useful starting point in such a study. Separate programming models were developed for each of six case study farms. Solution of these models and subsequent sensitivity tests yielded information on the optimal levels of tractor and animal use for each farmer under a variety of conditions. Conclusions were then drawn regarding the factors which are most crucial to farmers' decision-making.

The objective function in the linear programming models used in the current study is the maximisation of the expected net value of farm-household production. This objective rests on the assumption that the decision maker is not influenced by the relative riskiness of the various activities. The importance of this assumption was investigated by developing quadratic versions of the programming models.

The elicitation of farmers' subjective beliefs and risk attitudes (utility functions) is necessary for full specification of quadratic risk programming models. Existing methods for eliciting utility functions were found inadequate in the study area (see section 4.4.5), so it was not possible to identify a single utility-maximising plan for each farmer. Instead, the range of risk aversion levels was identified within which a given 'efficient' plan was optimal.

The results of linear programming were used to assess Hypothesis 1, while the linear and quadratic model solutions were compared in order to evaluate Hypothesis 2. Finally, sensitivity analyses were carried out to investigate the effect of various assumptions in the models. The results of the case study models could then be generalised and implications derived for the wider population in the study area.

1.6 Outline of the Dissertation

Following this introductory chapter, a selection of previous mechanisation studies is reviewed in Chapter 2. Two main approaches are identified, according to whether the focus is on the 'consequences' or the 'determinants' of mechanisation.

Theoretical aspects of the techniques chosen for this study are discussed in Chapter 3. The theory and practice of linear and quadratic programming are critically evaluated and a few previous applications of these techniques are mentioned.

In Chapter 4, data requirements and data collection procedures are described. The study area, selection of a sample of respondents, and the difficulties encountered in data collection are also discussed.

The programming models developed for the current study are the focus of Chapter 5. The structure of the linear models is outlined and the activities, constraints and coefficients are briefly discussed. The procedure used in the estimation of variances and covariances is then described. Once certain difficulties had been overcome, the estimates were used to convert the linear programming models into quadratic risk programming models.

Results of solving the programming models are presented in Chapter 6. Mean-variance efficiency frontiers were derived for two alternative versions of the quadratic risk programming models. These frontiers are illustrated and discussed. The risk-neutral solutions are then investigated further in sensitivity analyses. Hypotheses 1 and 2 are assessed in section 6.4.

Chapter 7 is a summary of the research. Conclusions, implications and shortcomings of the study are suggested, and directions for further research identified.

Chapter 2

PREVIOUS MECHANISATION STUDIES

2.1 Introduction

Mechanisation is one of the primary areas of concern in the debate over the role of improved technology in agricultural development. Following Schultz's (1964) hypothesis that peasant farmers are rational in their resource allocation and in their response to incentives, it has been suggested that the regular provision of improved, profitable technologies is the key to alleviating rural poverty and stimulating national development. Hayami and Ruttan (1971) argue that the adoption of innovations is 'induced' by changes in relative factor prices. Consequently, government policies which affect these prices are potentially crucial in determining farmers' choices between alternative techniques (see Dillon 1979, p. 173). The historical experiences of the United States and Europe have been cited as evidence that the introduction of tractors and other mechanised farm implements is a crucial step in the development process (Hall 1973, Merrill 1975, Bergmann 1978). However, it is widely recognised that agricultural mechanisation may not achieve the desired gains in productivity, and may have unfortunate side effects particularly in labour-abundant areas (see section 2.2).

Considerable research efforts have been devoted to investigating the consequences of mechanisation in less developed countries (the 'consequences approach'; see Roumasset and Thapa 1983). Particular attention has been paid to the effects on productivity and yields and to the social implications of changes in labour requirements. An alternative to the 'consequences' approach is that which focusses on 'the determinants of the mechanization choice' (Roumasset and Thapa 1983, p. 377). The present study falls into this latter category, as do others

in which an attempt is made to model or explain farmer decision making (see section 2.4).

Many of the studies discussed in this chapter cannot be neatly categorised as following either the 'consequences' or the 'determinants' approach. For instance, most studies in which the focus is farmer behaviour also devote some space to a consideration of the consequences of this behaviour. However, the distinction between the two approaches is convenient for the purposes of a review of literature concerning mechanisation.

After a brief discussion of a few primarily historical or descriptive studies in section 2.2, the 'consequences' literature will be examined in section 2.3. The section comprises an overview of research methods used in such investigations, followed by a summary of research findings on (a) yield and productivity and (b) labour use patterns and other social factors. Policy conclusions drawn from these studies are compared in section 2.3.4, and some shortcomings of the 'consequences' approach noted in section 2.3.5.

The approach which focusses on the determinants of the adoption decision is discussed in section 2.4. The structure of the previous section is repeated, with subsections dealing with research methods, findings and policy conclusions.

Finally, in section 2.5, key features of the literature review are summarised and implications for the present study are drawn.

2.2 Historical or Descriptive Studies

Several articles in a work by Meij (1960) deal with the historical determinants of mechanisation. For instance, van Bath (1960) examines the economic conditions which favoured technological development from the early days of agriculture until the present. He concludes that relative prices, labour supply and land tenure systems have always been crucial, as they are recognised to be today. Heady (1960) identifies three main factors which encouraged the mechanisation of United States agriculture. These were (a) progress in agricultural engineering, (b) changing

capital/labour price ratios and (c) increasing farm income especially in the post-war years. Mitchell (1960) traces the historical development of improved technologies in Europe, and observes that advances in agriculture have generally been dependent on complementary advances in industrial capability. However, European agriculture has lagged behind industry largely because of the predominance of 'small' farms (below 50 ha).

The mechanisation experiences of Africa and Asia have also been discussed in the literature. Stout, Kline, Green and Donahue (1973) describe the prevailing situation in Equatorial Africa. They note the failures of several 'imported' mechanisation projects, and stress that the existing social structure must be taken into account if undesirable effects are to be avoided. McColly (1973) summarises the situation in the Asian region. Pointing to successes in such countries as Japan and Taiwan, he concludes that mechanisation could play a crucial role in increasing productivity, while not necessarily causing labour displacement. Tsuchiya (1976) focusses specifically on Japan. Two distinct phases are identified in the rapid postwar mechanisation of Japanese agriculture. The first phase, from 1955 to 1966, predominantly involved the introduction of the power tiller (hand-tractor) onto small farms. After 1966, large farms were mechanised with transplanter and combine-harvesters. Tsuchiya concludes that further progress with mechanisation would require the decline of the small farm sector.

The Chinese experience with mechanisation has also attracted much interest. Yamamoto (1978) and Stavis (1978) give separate historical accounts of the evolution of mechanisation policy after the 1949 revolution. This policy was inextricably linked with developments in political and social thought among ruling party members. The importance assigned to mechanisation as an instrument of economic and social control has been summarised as follows (Li Kuan-heng 1972, quoted in Stavis 1978, p. 5):

Agricultural mechanization is not merely a way of increasing production, but is part of a broad rural policy. It helps consolidate socialism in the rural areas, helps develop economic forces, helps consolidate the worker-peasant alliance, and helps eliminate the difference between the city and countryside.

The Chinese experience is mentioned again in section 2.3.3.

2.3 The 'Consequences' Approach

The large volume of literature in which the impact of mechanisation is discussed precludes a detailed review of individual works. Instead, key features of over forty references are summarised in Table 2.1. It should be noted that the consequences attributed to mechanisation depend to some extent on the authors' definition of 'mechanisation'. Some authors focus solely on tractors, while others include mechanical threshers, irrigation pumps and so on. The third column of the table ('machine type') is aimed at clarifying the usage of the term in each case.

A brief review of the references listed in Table 2.1 is provided in the following subsections.

2.3.1 Research methods

It will be seen from Table 2.1 that the methods used in empirical research range from simple tabulation and description of survey results through to complex model building and simulation analyses. It is convenient to regard the choice of research method as a form of decision tree or flow chart, as illustrated in Figure 2.1.

Cross-sectional surveys, in which various categories of non-mechanised and mechanised farms are sampled, are more common than time-series ('before' and 'after') surveys. Notable exceptions are the on-farm experiments carried out by researchers of the International Rice Research Institute (Banta 1979, International Rice Research Institute 1983). The tabulation of survey data and the verbal or statistical description of such data is the main objective of some studies (National Council of Applied Economic Research 1973, Verma 1978, Bautista and Wickham 1979, Aguilar et al. 1983, Gill 1983, International Rice Research Institute 1983, Maamun et al. 1983, Saefudin et al. 1983). In other cases, this is merely the first stage of analysis. For instance, many authors then proceed to partial or whole farm budgeting (sometimes supplemented by production function analysis) in order to examine the

Table 2.1

Summary of Literature Concerning the Consequences of Mechanisation

Author and Date	Study Area	Machine Type	Method	Findings: yield, productivity, intensity	Findings: social / labour	Policy
Barker 1960	-	Machines	Theoretical	Generally little direct effect, but complementarity with other improved technology may affect yield. Deeper and more thorough cultivation or cultivation of marginal lands, improved timeliness to allow double cropping or loss reduction, release of fodder land for cultivation, may all contribute to production increases.	-	-
De Wilde 1967	Tropical Africa	Motorised or tractor drawn equipment	Theoretical	Potential for increasing area planted or improving timeliness (two objectives may conflict). New land must be cleared more thoroughly if tractors are to be used. Continuous cultivation is then more likely than frequent fallowing, because of the costs of land clearing.	Peak labour bottlenecks may be overcome but others may develop if more land is cultivated.	An International Centre is needed to monitor, evaluate and coordinate agricultural mechanisation in Africa.
Bose and Clark 1969	Pakistan	Tractors	Cash flow budgeting, BCA	Probably no difference, unless timeliness is crucial. Otherwise, bullocks can prepare land as well as tractors, but in more time.	Reduction in farm labour requirements so tenants evicted.	Exchange rates, low interest loans and price support cause wide divergence between private and social net benefits. Emphasis should initially be on biochemical technologies.
Wills 1972	Uttar Pradesh, India	Machines	LP	Entire technology package (biochemical and mechanical) causes increase in cropping intensity.	Machinery adoption will offset the positive employment effects of biochemical technology; income disparity between farmers and labourers will increase.	Government should be cautious in promoting labour-displacing machinery.

Table 2.1 continued

Hall 1973	-	Machines	Theoretical	Yields can increase through better water control, soil preparation, weed and insect control, harvest and post-harvest processing. Timeliness enhances yields.	Mechanisation may be a cause of or a response to rural-urban migration.	'Agricultural mechanization should be introduced as necessary to increase desired agricultural production and generate employment or to take the place of labor absorbed by industry' (p. 2).
National Council of Applied Economic Research 1973	India	Tubewells, tractors, threshers	Tabulation of survey data	Significant yield effects as level of mechanisation increases. Cropping intensity increases, especially on small farms.	Labour input / ha is higher on large and small farms with tractor, tubewell and thresher than on non-mechanised large and small farms, but lower on medium farms. Total labour use declines when tubewell-owning farms acquire a tractor. Displacement is usually of male family labour, who then spend more time in managerial capacity on their farms.	-
Jegatheesan 1974	Muda, Malaysia	Hand tractors, 4-wheel tractors and machines in general	Policy summary	Mechanisation essential for achievement of double cropping goal.	Benefits of increased production will outweigh costs of labour displacement.	-
Kuthiah 1974	South India	Tractors	Summary of other studies	(Various)	(Various)	Punjab results should not be taken as representative of all India.
Yeop and Noah 1974	Muda, Malaysia	Machines	Policy summary	Mechanisation essential for achievement of double cropping goal.	Mechanisation essential in overcoming seasonal labour shortages.	Promote development of All-Terrain-Vehicle (ATV) suitable for Muda conditions and with low cost to farmers.
Ahmed 1975	Pakistan Punjab	Tractors	LP	Cropping intensity increased only on farms with tubewell.	Vary according to system of irrigation and package of mechanisation. Employment decreased on farms without tubewell, increased if tubewell used.	Correcting price distortions for machines and output 'is not likely to affect the pace of mechanization' (p. 64).
Desai and Gopinath 1975	Gujarat, India	Tractors	Budgeting, LP; different constraint levels for bullock vs. tractor farms	35% higher cropping intensity, 16% higher yield on tractor farms than on bullock farms.	-	Nitrogen constraint more restrictive than power constraint.

Table 2.1 continued

Gotsch 1975; Gotsch and Falcon 1975	Pakistan Punjab	Persian wheel, tubewells	LP and mixed integer LP	-	Less distorted factor pricing would improve social efficiency and income distribution.
Hanumantha Rao 1975	Indian Punjab	Tractors	Budgeting, BCA	Output has increased, but maybe would have increased more with technologies other than tractors, e.g., HYVs.	Rising wages make tractors attractive for large farmers; hired labour decreased, widening income disparities between large landowners and landless labourers.
McInerney and Donaldson 1975	Pakistan	Tractors	'Before' and 'after' BCA	Cropping intensity increased especially on small farms. No clearcut yield effect.	Labour use/acre declined by 40%; 4.2 tenant families were displaced per farm. 'Mechanization programs along the lines of those already attempted should no longer be advocated' (p. 83). Mechanisation should only be promoted with complementary policies designed to minimise adverse effects, e.g. constraining land enlargement, avoiding labour/capital ratios which favour capital, including mechanisation in a 'package' of new technology (chemicals, irrigation, etc); encouraging multi-farm use or group ownership.
Makhijani and Poole 1975	Developing countries	Machines	Energy analysis	Potential for yield increases where power constraints are severe.	Removal of seasonal labour shortages 'will deprive the poorest people of their only source of economic power' (p. 79).
Merrill 1975	Developing countries	Tractors and machines in general		Little effect on yields in early stages of mechanisation; slight increase in multiple cropping.	Reduction in labour requirements not offset by creation of employment in machine industry. Landholding size may increase and tenants be displaced unless government policies prevent this. Large landholders benefit more from policies which favour mechanisation.
					Mechanisation is 'continuous' and 'inevitable' but its speed and direction can be altered by public policies and programs.

Table 2.1 continued

Tsuchiya 1976	Japan	Power tillers and large scale machines	Economic history	Main aim was cost reduction rather than yield increase. Labour productivity increased on large farms but not on small farms.	-	Increase in farm size and large-scale mechanisation are essential to increase labour productivity, but slow progress is likely.
Singh and Day 1977	Punjab	Tractors	LP	-	Labour displacement 'inevitable'.	-
Bergmann 1978	Germany and India	Tractors and machines in general	Historical	Germany: yield increases cannot be attributed solely to mechanisation. India: mechanisation can contribute to rapid increase in agricultural production.	Germany: Agricultural workforce declined; industrial workforce increased. India: Tractor permits transition from large sharecropped property to owner cultivation or management. This is 'part of the general transformation from an agrarian to an industrial society' (p.108). In long run, unemployment will not increase.	India: Local tractor production necessary plus thorough training in driving, maintenance and repair. Multi-farm use by Government or cooperative agencies desirable.
Rinswanger 1978	South Asia	Tractors	Comparison and evaluation of previous studies	No 'evidence that tractors are responsible for substantial increases in intensity, yields, timeliness, and gross returns.'	Evidence of labour displacement.	Often considerable divergence between private and social net benefits due to artificial exchange rates and tractor and fuel subsidies.
International Rice Research Institute 1978	China	Machines	Field study report	Rapid turnaround time between crops (2 weeks) allowed double or triple cropping.	Chinese estimate that labour requirement per ha has declined from 400 to 200 man-days per crop. However, because of double or triple cropping, annual requirements have changed little. In any case, surplus labour is regarded as an asset, which can be used in other productive tasks.	Water control, power and labour availability and organisation of labour were the crucial differences between the productive system in China and elsewhere in Asia.
Sinaga 1978	West Java, Indonesia	Hand-tractors	May increase intensity in labour scarce areas (not Java).	Each tractor used resulted in Rp. 1 million loss to landless labourers.	Land preparation cheaper with tractor because of low interest rates and artificially favourable exchange rate.	

Table 2.1 continued

Stavis 1978	China	Machines	Historical	Agro-technical aspects largely overlooked before 1958. Under Machine Tractor Station system, yields increased (plowing was more uniform and deeper). Potential yield effect, but must satisfy natural constraints, e.g. timeliness, conformity to local cultivation practices.	Mechanisation policy implemented as part of social policy; Machine Tractor Stations designed to 'consolidate the collective economy' (p. 72); mechanisation emphasised during Cultural Revolution. Benefits of mechanisation 'are shared widely throughout the rural community because of ... collective ownership' (p. 263).	'The notion that development can proceed by itself without political leadership is certainly challenged by China's experience' (p. 265). Modern technology can serve everyone, if accompanied by suitable political and social policies.
Thiesenhusen 1978	Developing countries	Machines	Theoretical	-	Degree of displacement depends on (a) crop type, (b) cropping pattern, (c) type, quantity and uses of machinery, (d) cropping intensity, (e) land tenure and labour organisation. Mechanisation could have a beneficial employment effect if: (a) intensity or extent of land use increases, (b) if alternative productive on-farm employment is available, (c) if machinery is locally manufactured, employment in industry and service sectors will increase, (d) if mechanisation increases production, then scope for harvest and post-harvest employment widens.	-
Verma 1978	Rajasthan, India	Tractors	Tabulation of cross-sectional survey data	Increase in cropping intensity on large farms.	Labour requirement reduced on small and medium farms, but increased overall on large farms because of increased cropping intensity.	Should encourage selective mechanisation in favour of large farms.
Banta 1979	Philippines	Hand tractors	Tabulation of on-farm experiment results	Yields with hand-tractor lower than with manpower only or man and animal power.	For rice, 225 hours of labour/ha were used on farms with a hand tractor, compared to 455 for carabao farms and 660 for hand labour farms.	-

Table 2.1 continued

Bautista and Wickham 1979	Philippines	Tractors	Tabulation of survey data	No significant yield differences.	Farmers' leisure time did not increase significantly.	-
Hamid 1979	Pakistan	Tractors, hand tractors	Budgeting	Evidence points to a substantial increase in yields as a result of mechanical cultivation' (p. 211). Cropping intensity increases, land freed from fodder production can be cultivated.	Large tractors displace labour, but hand tractors displace only animals and generate more employment. Small farmers can afford handtractors, and so income disparities would lessen.	Mechanisation is essential for farm intensification, but priority should be given to 2-wheeled 10hp hand tractors.
Pudasaini 1979	Nepal	Tractors	Production function analysis	Yields higher on mechanised farms than non-mechanised farms, but differences not attributable solely to tractor. Tractors allowed higher cropping intensity.	Employment higher on mechanised farms. Tractors did not displace labour, while pumpsets increased it.	-
Roy and Blase 1979	Indian Punjab	Tractors	Production function comparison between tractorised and non-tractorised farms	No significant direct effect, but more intensive cultivation possible; hence, upward shift in production function.	Total labour use unchanged. Hired labour use increased. Family labour use decreased.	Tractor use is unlikely to become widespread and can easily be controlled by public policy.
Venkatappiah 1979	India	'Means for increasing production'	Theoretical	Yield increases because of timely planting.	Agricultural mechanisation creates significant employment in industry. Displaced farm labour can usually find alternative work.	-
Wicks 1979	-	Machines	Theoretical	-	-	Appropriate technique for modelling mechanisation consequences is Multiperiod Recursive Integer Programming.
Agarwal 1980	Indian Punjab	Tractors	Critique of Roy and Blase (1979) using same data	Positive effect on cropping intensity, but farm productivity does not increase significantly.	Labour time requirements significantly reduced, though small effect on number of workers employed.	The Roy and Blase results must not be used to draw policy implications.
Hamid 1980	West Java, Indonesia	Hand tractors	BCA (NPV, B/C and IRR criteria)	Higher cropping intensity.	Depends on which cultivation system is used (15-21 days or 21-75 days). Employment opportunities increase with higher intensity.	-

Table 2.1 continued

Salam 1981	Pakistan	Tractors	Production function analysis	Tractors contribute significantly to increased wheat yields.	Overall labour use higher on bullock farms but more labour hired on tractor farms.	-
Atwal 1982	-	Machines	Energy input-output ratios	-	-	Energy efficiency of sugar cane production has improved relative to paddy and wheat production.
Fegan 1982	Luzon, Philippines	Hand tractors	Descriptive	Hand tractor use increased yield through timeliness of planting and double cropping.	Mostly farmers' own labour displaced.	-
Aguilar, Camacho, Generalla, Moran, Sison, Tan and Wicks 1983	Philippines	2 and 4 wheel tractors	Survey; record keeping; statistical analysis	No direct impact on yields or cropping intensity.	Lower labour use on mechanised farms because of lower use of family labour. Hired labour was significantly lower only for land preparation.	-
Ahmed and Herdt 1983	Philippines	Various machine types	Semi-closed input-output model	Irrigation is more effective than mechanisation in increasing output.	Labour use decreased, income of hired labourers decreased.	Emphasis should be on increased irrigation intensity rather than on mechanisation.
Gill 1983	Bangladesh	Tractors, power tillers	Statistical analysis	Tractors did not improve timeliness or affect cropping intensity. Even in experiment station trials, mechanisation did not significantly affect yields.	Hired labour decreased for land preparation but not for weeding. Further indirect displacement may occur if mechanisation causes an increase in average farm size.	Improved supply and performance of draught animals is more appropriate than mechanisation.
Jabbar, Bhuiyan and Bari 1983	Bangladesh	Power tiller		Cropping intensity increased, but no effect on cultivated area.	Regular labour decreased, tenants were evicted and tenure status changed as a result of power tiller use. Rich farmers stood to benefit at the expense of small and marginal ones.	-
Jayasuriya, Te and Herdt 1983	Philippines	Various categories of machinery	Tabulation of survey results and literature review	Apparent yield and intensity effects are often attributable to differences in fertiliser, irrigation, etc. In this study, no significant differences in yield, intensity or turnaround time between mechanised and non-mechanised farms were evident.	Machine-related activities do not fully offset the negative on-farm employment effects.	-

Table 2.1 continued

Lockwood, Munir, Hussain and Gardezi 1983	Pakistan	Tractors	Reviews of two previous studies	No apparent increases in farm productivity either by increasing cultivated area or by increased intensity or yields.	Reinforcement of inequitable traditional rural power structure, reduced earnings of rural landless.	Present mechanisation program has very high costs.
Luwu Area and Transmigration Development Project and International Rice Institute 1983	Luwu, South Sulawesi	Hand tractors and 4 wheel tractors	Tabulation of record keeping results from on-farm experiments	Tabulation of No perceived yield or cropping intensity effects.	Family labour use declined and hired labour increased for land preparation.	A large latent demand exists for tractor services at or near 1982-83 prices.
Maamun, Sarasutha, Hafsa, Bernsten, Sinaga and Wicks 1983	South Sulawesi (Sidrap and Pinrang)	4 wheel mini-tractors	Survey, record keeping, tabulation	After adjusting for differences in fertiliser use, conclude that mechanisation has no positive effect on yields. Cropping intensity increased slightly in rainfed areas but not in irrigated areas. Complementary inputs are required for further increases.	Labour for land preparation in wet season double on non-mechanised farms, but little difference in dry season. Overall, mechanised farms used less family labour but hired the same or more labour for certain operations.	-
Saefudin, Sivocosumarto, Bernsten, Sri Bagya, Lingard and Wicks 1983	West Java	Hand tractors	Survey, record keeping, statistical analysis	Any yield increases on mechanised farms could be explained by higher use of inputs other than machinery. Similarly, no clear impact on cropping intensity.	Significant decline in labour use/ha on mechanised farms.	-

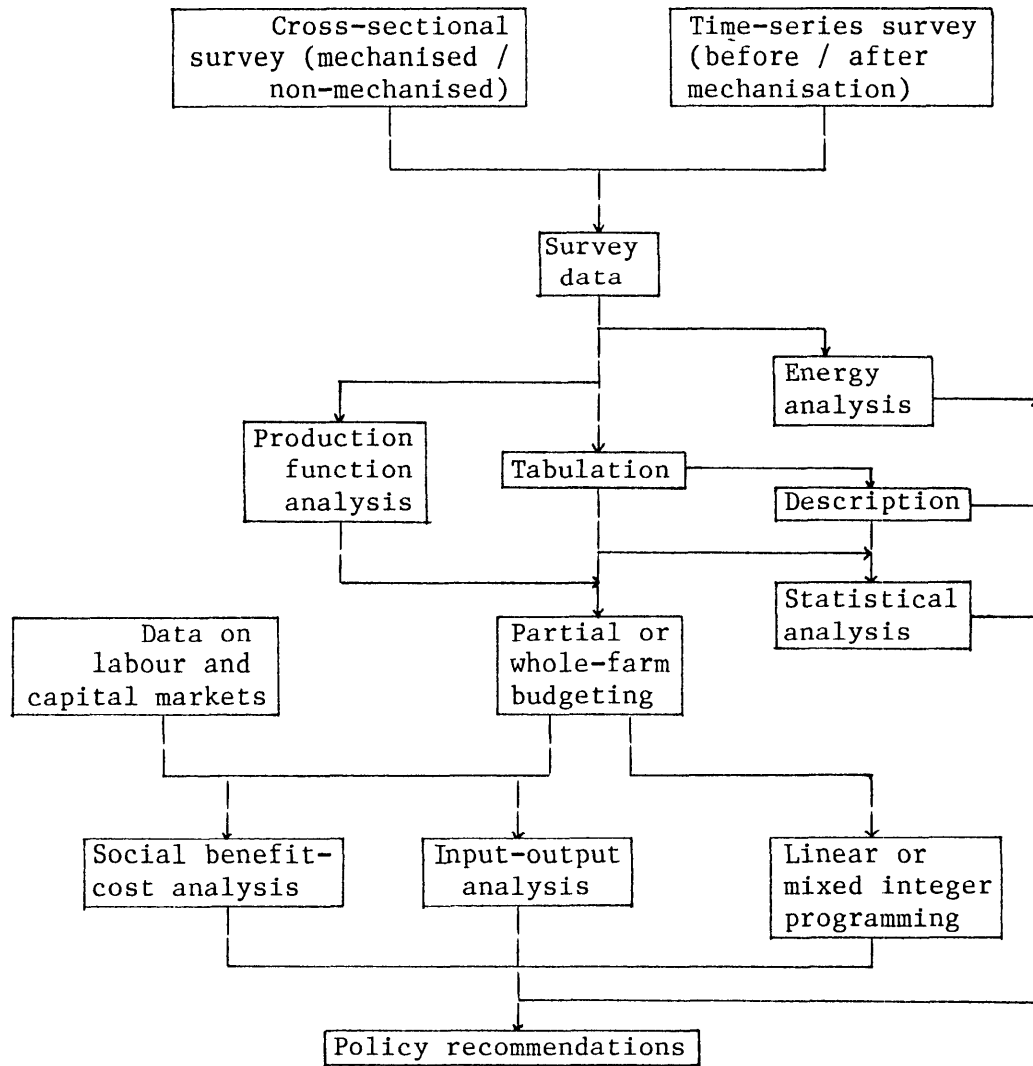


Figure 2.1 Flow-chart of Procedures in Mechanisation Research

private profitability of machine use or purchase (Hamid 1979, Pudasaini 1979, Roy and Blase 1979, Agarwal 1980, Salam 1981,). The budgeting exercise may then be expanded into a full social benefit-cost analysis which takes into account any distortions in the prices of capital and labour and their effects on the private and social value of mechanisation (Bose and Clark 1969, Hanumantha Rao 1975, McInerney and Donaldson 1975, Hamid 1980). Alternative analytical methods are input-output modelling (Ahmed and Herdt 1983) and linear or mixed integer programming (Wills 1972, Ahmed 1975, Desai and Gopinath 1975, Wicks 1979). The latter method also lends itself particularly well to the investigation of the adoption decision, as discussed in section 2.4.

An alternative research method occasionally used in mechanisation studies is energy analysis. Here, the energy values of alternative production technologies and the energy output-input ratios of different cropping patterns are compared (Makhijani and Poole 1975, Atwal 1982). This approach has been criticised by Edwards (1976, p. 189) on the grounds that several 'implausible assumptions' are required. These are:

... energy available from food is an adequate measure of its value to local and overseas consumers; inputs other than energy used in food production can be treated as though they are costless; and inputs of x joules from each of two energy sources can be treated as identical regardless of differences between them in scarcity, convenience and pollution generated ...

2.3.2 Research findings: effects on cropping intensity and yields

The potential of tractors and other agricultural machinery for increasing cropping intensity and yields is summarised in theoretical studies such as Barker (1960), de Wilde (1967), Venkatappiah (1979) and Hall (1973), as well as in most empirical studies. Briefly, the argument as far as tractor use is concerned is that land preparation may be accomplished more speedily with a tractor than with human and animal power alone. Timely planting may therefore be assured (thus avoiding losses caused by delayed planting), and the shorter turnaround time between crops may permit an increase in cropping intensity. Total cropped area may also be expanded, either by the ploughing of marginal lands or by the cultivation of land previously reserved for animal fodder. It is also sometimes argued that the quality of land preparation

is superior when tractors replace animals, and that this in itself causes lower weed infestation and higher crop yields.

While the above arguments may appear plausible, the empirical evidence is less convincing. Binswanger (1978) identifies two approaches to the tractorisation issue. Tractors might be regarded as making a 'net contribution' to the production process or as merely 'substituting' for animal power. He concludes that the South Asian evidence predominantly supports the latter view. Significant yield effects have been reported in several studies (for example, Desai and Gopinath 1975, Hamid 1979) but closer scrutiny suggests that these effects can be explained by differences in irrigation and fertiliser levels, and should not be attributed to the tractor (Binswanger 1978, Jayasuriya et al. 1983).

2.3.3 Research findings: social effects

The social issue which has received most attention in the mechanisation literature is labour displacement. While most of the authors listed in Table 2.1 agree that the use of tractors for particular tasks reduces the labour requirements for those tasks, there is less consensus on the wider employment implications of tractor use.

As Thiesenhusen (1978) asserts, the prevailing agricultural and social systems are crucial determinants of the effect on total labour use and also of the relative impacts on specific groups in the labour force. The fate of redundant draught animals may also be a significant factor. Labour needs will generally decline more if the animals are sold than if they are kept for other non-mechanised operations, breeding purposes or milk.

Labour displacement is not usually regarded as a social cost if alternative employment opportunities are available. Bergmann (1978) and Venketappiah (1979), for instance, consider mechanisation and the consequent decline in the agricultural labour force to be a necessary stage in economic (that is, industrial) development. In China, it has been observed that any labour displaced by mechanisation was always assigned to other productive tasks (International Rice Research Institute 1978). Similarly, in areas where the main impact of mechanisation has

been a reduction in family labour requirements, more time has become available for management and supervision, alternative on-farm tasks or off-farm employment (National Council of Applied Economic Research 1973, Roy and Blase 1979, Fegan 1982, Aguilar et al. 1983, International Rice Research Institute 1983, Maamun et al. 1983). The role of the tractor in overcoming seasonal labour shortages is stressed by de Wilde (1967), Jegatheesan (1974) and Yeop and Noah (1974). Thiesenhusen (1978) indicates other potential employment benefits of mechanisation, particularly where the machines are produced and maintained locally.

Labour displacement is generally considered to be socially undesirable in areas of high unemployment, particularly where large numbers of tenants and landless labourers are disadvantaged (Bose and Clark 1969, Hanumantha Rao 1975, Jabbar et al. 1983, Lockwood et al. 1983). Evidence of severe displacement is presented by McInerney and Donaldson (1975), Binswanger (1978), Sinaga (1978), Ahammed and Herdt (1983) and Saefudin et al. (1983). On the other hand, Pudasaini (1979) and Gill (1983) found that overall labour use was not significantly lower on tractorised farms than on non-tractorised farms.

2.3.4 Summary of policy conclusions

The conclusions and policy recommendations formulated in the literature are mostly specific to the area or subject matter of each study. Nevertheless, a few recurring themes may be noted. For instance, among those studies which report the results of social benefit-cost analysis (Bose and Clark 1969, Ahmed 1975, Hanumantha Rao 1975, McInerney and Donaldson 1975, Binswanger 1978, Sinaga 1978), the common feature is a recommendation that the prices of capital and labour (interest rates, machinery prices, agricultural wages) should be allowed to stabilise at their market values instead of being artificially determined by government policy. The divergence between private and social benefits and costs would thus disappear. If mechanisation were socially undesirable, then it would also prove to be privately unprofitable.

A few researchers (Hall 1973, Tsuchiya 1976, Bergmann 1978, International Rice Research Institute 1983) have encouraged national governments to promote full-scale agricultural mechanisation. Others urge caution in the form of selective mechanisation (Verma 1978, Hamid 1979), inclusion of mechanisation in a broader technological 'package' (McInerney and Donaldson 1975), or a change of emphasis away from mechanisation towards alternative policies (Bose and Clark 1969, Wills 1972, Ahammed and Herdt 1983, Gill 1983, Lockwood et al. 1983).

2.3.5 Shortcomings of the 'consequences' approach

All the literature reviewed so far in section 2.3 focusses on the consequences of mechanisation rather than on the forces which determine farmers' decisions to mechanise. Criticisms of the 'consequences' approach by Roumasset and Thapa (1983) are summarised in this subsection.

Roumasset and Thapa (1983) base their argument on the observation that the 'effects' of technological changes such as tractor use may very easily be confused with the determinants of such changes. For instance, a change in factor prices may 'induce' technological change (Hayami and Ruttan 1971) and also cause other changes which are then mistakenly assumed to be the result of the new technology. Referring specifically to Binswanger's 'substitution' versus 'contribution' dichotomy, they claim that the distinction depends to a great extent on the causes of the tractor use (Roumasset and Thapa 1983, p. 378).

For example, if tractorization is induced by the rising relative cost of animal to mechanical power, then tractors may approximately substitute for animal power. If tractorization is induced by increasing land scarcity then tractors may contribute to productivity by lowering the cost of timely land preparation.

The authors conclude that investigations of the effects of mechanisation are redundant. Since farmers are privately efficient, their mechanisation decisions will be socially beneficial so long as there are no significant market imperfections. Therefore, the only mechanisation topic worthy of research is the analysis of farmer decision-making.

Roumasset and Thapa's warning about confusing cause and effect is worth bearing in mind in relation to the studies reviewed in section 2.3. Nevertheless, it seems unfair to dismiss categorically all such studies as worthless or misguided. In a perfect market, it might be expected that socially undesirable consequences of mechanisation will be minimal. In the highly imperfect markets which actually exist, it may be more fruitful for researchers to alert policy makers to problems associated with mechanisation than to recommend major restructuring of the economic system.

The Roumasset and Thapa (1983) article provides a convenient introduction to another major body of research work on mechanisation. This is the 'decision theoretic' or 'determinants of adoption' approach. It is reviewed in the following section.

2.4 The 'Determinants' Approach

Important features of a number of references concerned with the determinants of mechanisation are tabulated in Table 2.2. Several studies mentioned in section 2.3 have also made a contribution to the 'determinants' debate, and so are included in Table 2.2. A brief review follows.

2.4.1 Research methods

Many of the studies summarised in Table 2.2 are of a theoretical or descriptive nature, rather than reporting empirical research (Hunt 1960, Lonnemark 1967, Wilkinson and Hall 1973, Mosher 1974, Culpin 1975, Balis 1978, Chancellor 1978, Harwood 1979, Morris and Pollard 1979, Fegan 1982). Among the empirical studies, the general pattern of research techniques appears to follow that depicted in Figure 2.1. Several studies proceed no further than tabulation of survey data (Alviar 1974, Kahlon and Singh 1978, Alviar 1979, Bautista and Wickham 1979, Hafsah and Bernstein 1983, Luwu Area and Transmigration Development Project and International Rice Research Institute 1983). Other authors use statistical tools such as correlation and regression (Hamilton 1967, Hanumantha Rao 1975, Nair 1980, Roumasset and Thapa 1983). Most of the works in which programming or simulation methods are used are included in

Table 2.2
Summary of Literature Concerning the Determinants of Mechanisation

Author, Date	Study Area	Machine Type	Method	Factors Affecting Machine Use	Policy
Hunt 1960	-	Machines	Theoretical (optimality principles)	The point of tangency between the cost curve and the isoproduct curve is the optimum technological combination, but factor indivisibility restricts actual choice.	-
Hamilton 1967	Queensland	Machines	Regression	'Area of crops', 'time taken for cropping operations', 'level of investment in plant and machinery' and 'expenses incurred in operating machinery' influence machinery use (p. 5).	-
Lonnemark 1967	Developing countries	Machines	Descriptive	Adoption is affected by: prices of farm produce and machinery; wages and supply of labour; credit availability; agricultural incomes; extension services; educational standard of farmers; degree of cooperation between farmers; general socioeconomic conditions of the country (e.g. land tenure).	Need for 'enlightened extension work and thorough demonstration among the farming community'.
Clements 1969	Brazil	Machines	Sociological fieldwork	Adoption is inhibited by: 'attitudes and values generated within the system of large estates and transmitted to successive generations of landowners', 'apprehensions' or 'misgivings' about national government policies, slow progress with agrarian reform (p. 82).	-
Winkelman 1972	Mexico	Tiller, tractor	Linear programming	Mules generate most income on 4-5 ha farms; tiller on 8 ha farms. When leisure preferences included, tiller preferred on all farm sizes. Greater speed of tiller permits more land tillers to be planted in the most profitable crop (sesame). Oxen and tractors are never preferred.	Emphasise labour use and draught animals or small land tillers.
Wilkinson and Hall 1973	Latin America	Machines	Theoretical	Deterrents to mechanisation: lack of infrastructure, low agricultural incomes, 'heavy lands and small farms', 'low educational and technical skill of laborers and farmers', 'unfavourable economic policies', 'low productivity' (p. 96).	Test suitability of machines before importing or manufacturing.

Table 2.2 continued

Mosher 1974	South-East Asia	Various categories	Summary of conference proceedings	Influences on mechanisation include: topography, degree of irrigation, crop type, degree of farm commercialisation, power and human labour requirements, reduction of drudgery, demonstration of modernity (i.e. prestige), ability to perform new tasks, e.g. double-cropping, pest and disease control, potential to increase total family income, reduction in time required for care of draft animals, avoidance of problems associated with labour hire or tenancy. Constraints on mechanisation include insufficient increase in expected income to offset risks and uncertainties of adoption, lack of credit, expected instability in farm product prices (pp. 337-8).	'Actively promote those forms of mechanization that facilitate multiple cropping', explore non-mechanical alternatives, support agricultural engineering research, explore social, political and economic aspects of organisations to promote and support mechanisation, refrain from policies which profit manufacturers or importers at public expense, limit the number of makes and types of farm equipment, require manufacturers or importers to meet specified standards for servicing and spare-parts availability (pp. 42-3).
National Council of Applied Economic Research 1974	India	Tractors	Single-equation demand model for demand estimation	Demand for tractor services will increase but demand for ownership will decline.	-
Ahmed 1975	Pakistan Punjab	Tubewells and tractors	LP as in Gotsch and Falcon (1975), but allowing tractor purchase	Tractor purchase is unprofitable unless a tubewell is available (but a constraint in the model allows only a tractor, rather than additional bullocks, to satisfy the extra power requirements following tubewell purchase).	-
Culpin 1975	-	Machines	Theoretical	Small farm size is a major obstacle to mechanisation, but use of second-hand machinery, hiring and contract work reduce differences in investment levels between small and large farms.	-
Gotsch 1975	Pakistan Punjab	Persian wheel	LP	Animal power is not limiting if there is no Persian wheel, but becomes extremely valuable when wheel is introduced. Net revenue increases with wheel.	-
Gotsch and Falcon 1975	Pakistan Punjab	Tubewell	LP matrix as above, modified to include tubewells and HYVs	Use of tubewell radically changes optimal cropping pattern and increases revenues.	Develop government water-pricing policy.

Table 2.2 continued

Gotsch and Yusuf 1975	Pakistan Punjab	Tubewells, tractors	LP matrix as above, but with integer restrictions	Extra bullocks preferable to a tractor to ease tubewell labour shortage.	Development of smaller-scale machinery would be beneficial.
Hanumantha Rao 1975	Indian Punjab	Tractors, pumpsets	Correlation, regression	High correlation between tractor ownership and per capita income, wage rate, percentage of area irrigated, percentage of males aged 15-59 in agricultural workforce (reflecting low total participation rate and hence available labour supply). Also high correlation with urbanisation and low correlation with normal rainfall. For pumpsets, similar pattern but smaller magnitude of correlations.	-
Sharma 1976	Punjab	Various sizes of tractors and other mechanised equipment	LP	Optimal plan is complete mechanisation with 14hp tractor and 5hp electric motor. Custom hire increases income.	-
Balis 1978	India	Small 4-wheel tractors and equipment	Description of tractor Evaluation Project	Tractor use adopted because of economic benefits, and to encourage sons to remain on farm.	High benefits, but need adequate training and servicing.
Chancellor 1978	South and South-East Asia	Tractors	Descriptive	Benefits of tractor use: potential cash income from custom hiring; reduced drudgery; better timeliness; opportunities for alternative productive activities.	Custom tractor operation should be encouraged.
Kahlon and Singh 1978	Punjab	Tractors	Tabulation of survey data	Low tractor use related to: 'lack of tractor accessories'; 'lack of precision in repairs'; 'presence of bullocks on tractor farms'; 'slow adoption of some mechanised operations'; 'non-remunerative social use' (e.g. family transport); inappropriate tractor size for size of farm (pp. 285-6).	Farmers must develop schedules for tractor operation so as to utilise surplus capacity. More farmer training needed.
Alviar 1979 (also 1974)	Philippines	Hand tractors	Tabulation of survey results	Main reasons for purchase: problems of carabao maintenance; savings in time; government subsidy on tractor purchase; possibility of custom hire.	Mechanisation more likely to succeed in irrigated areas with above-average farm size.
Bautista and Wickham 1979	Philippines	2 and 4 wheel tractors	Tabulation of survey results	In irrigated area, main cause of tractor hire was ease of land preparation and consequent lessening of workload between crops. In rainfed area, timeliness was most important.	-
Harwood 1979	Developing countries	Machines	Theoretical	Tractors adopted because of: increased power needs following increased cropping intensity; involvement in market economy; sufficient cash flow, relatively high living standard (i.e. income above basic needs). Rational economic decision based on perceived costs and benefits.	-

Table 2.2 continued

Horris and Pollard 1979	Developing countries	Small tractors	Theoretical	Private smallholder demand depends on farm size, production system, adequacy of existing power sources, expected net income with and without tractor, costs of purchase and use, opportunity cost of tractor investment (i.e. net benefits of alternative power sources and other investments) (p. 4).	More cooperation needed between engineers and economists, sociologists, etc.
Singh 1979	India	Tractors and accessories	Cost analysis from survey data	Tractor costs per cropped acre and per hour decline as farm size increases, tenurial status has no effect on tractor use.	-
Nair 1980	Various	Tractors	Regression	Main determinants of tractor use: tractor prices; ratio of prices received to prices paid by farmers; level of economic development; farm wage rate.	-
Gonzales, Herdt and Webster 1981	-	Power tillers, 4 wheel manual rice transplanters, irrigation pumps, portable rice threshers	Simulation analysis (sector model)	Research results will be obtained on the effects on machine sales of alternative policy instruments (credit subsidies, machinery taxes and tariffs, fuel tax and price).	-
Fegan 1982	Philippines	Hand tractors	Descriptive	Tractor adoption relieves 'year-round buffalo maintenance drudgery' (p. 14). Cheap government credit encourages purchase.	-
Hafsah and Bernsten 1983	Sidrap and Pinrang, South Sulawesi	Mini-tractors (4 wheeled)	Tabulation of survey results	Tractors purchased for cultivation of own land; also because of the possibility of custom hire, timely planting, land preparation, reduced need for hired labour and availability of credit.	Tractors not economically viable because of frequent breakdowns and short working life.
Luvu Area and Transmigration Development Project and International Rice Research Institute (1983)	Luvu, South Sulawesi	Hand tractors and 4 wheel tractors	Tabulation of survey results	Tractors provide improved tillage quality, timely planting and possibility of alternative work.	Monitor use and performance of tractors owned by Farm Cooperative Centre; assess nature of demand curve for 2-wheeled tractors.
Roumasset and Thapa (1983)	Nepal	4 wheel and hand tractors	Statistical analysis, expected accounting profits model	'It is quite plausible that both mechanical and animal power are privately efficient for those who choose to use them' (p. 391).	Tractor subsidies should be avoided.

Table 2.2 rather than (or as well as) in Table 2.1, since the focus is on optimal farmer decision-making (Winkelman 1972, Ahmed 1975, Gotsch 1975, Gotsch and Falcon 1975, Gotsch and Yusuf 1975, Sharma 1976, Gonzales, Herdt and Webster 1981, Roumasset and Thapa 1983). However, the results of social benefit-cost analysis have been reported in Table 2.1, since the main emphasis is usually on the consequences of mechanisation even when the rationality of private decisions is also assessed.

2.4.2 Research findings

The main findings of the research reviewed in this section are summarised in Table 2.2. Two broad categories of findings may be distinguished. In the first category, the economic, social and personal causes of the adoption or non-adoption of mechanisation are identified. These include relative factor prices, labour availability, potential for income generation, farm size and reduction of drudgery. Mosher's (1974) list is particularly comprehensive; see also Hamilton (1962) Lonnemark (1967), Wilkinson and Hall (1973), Alviar (1974) Culpin (1975), Hanumantha Rao (1975), Balis (1978), Chancellor (1978), Clements (1969), Kahlon and Singh (1978), Alviar (1979), Bautista and Wickham (1979), Harwood (1979), Morris and Pollard (1979), Nair (1980), Fegan (1982), Hafsa and Bernstein (1983) and Luwu Area and Transmigration Development Project and International Rice Research Institute (1983).

The second category of findings relates to the optimality of particular levels of mechanisation. The farmers' decision criterion is usually assumed to be the maximisation of a single goal such as net income or accounting profits. Ahmed (1975), Gotsch (1975), Gotsch and Falcon (1975) and Gotsch and Yusuf (1975) conclude that tubewells are beneficial to Punjabi farmers but that animals are generally preferable to tractors for satisfying agricultural power requirements. Sharma (1976), also in the Punjab, claims that full mechanisation is optimal. Winkelman (1972) models leisure preferences and finds these to exert considerable influence over the optimal power source.

With the large number of decision-making criteria identified by the authors in the first category, the modelling efforts of authors in the second category appear somewhat inadequate or at best oversimplified. This point will be addressed further in section 2.5 and again in Chapter 3.

2.4.3 Summary of policy conclusions

Policy recommendations formulated by the authors listed in Table 2.2 generally follow from their identification of the factors necessary for successful mechanisation. These include extension and training programs for farmers and machine operators (Lonnemark 1967, Balis 1978) and tests of the suitability of the machines both before and after adoption (Wilkinson and Hall 1973, Luwu Area and Transmigration Development Project and International Rice Research Institute 1983). Chancellor (1978) and Kahlon and Singh (1978) see a need for custom hire and careful scheduling so as to allow full utilisation of the machinery. Roumasset and Thapa (1983) urge the abandonment of tractor subsidies.

Recommendations based on the programming studies are derived from sensitivity analyses and from examination of the primal and dual solutions, which indicate the value of changes in the prevailing pattern of resource availability. Winkelman (1972) argues that labour, draught animals and small tillers should be given preference over large tractors, while Gotsch and Yusuf (1975) suggest that the development of small machines would be beneficial.

2.5 Implications for the Present Study

The intention in the present study is to model the decision-making process of a small number of farmers in order to examine their optimal levels of tractor use. This objective places the study within the category of research reviewed in section 2.4 under the label of the 'determinants' approach. Nevertheless, the works of authors with different approaches and objectives, discussed in this chapter under the heading of the 'consequences' approach (section 2.3) also have important implications for the present study. Meanwhile, the studies summarised in section 2.2 serve to place the mechanisation issue in its historical

context.

The diversity of research methods which have been used in mechanisation studies (see sections 2.3.1 and 2.4.1) suggests a need to justify the choice of method for the current study, as well as indicating the logical sequence in the analysis and presentation of results (tabulation, budgeting, programming). The first of these issues is addressed in Chapter 3, while the second is used as a guide in the organisation of Chapter 6 and associated appendices.

The 'substitution' versus 'net contribution' debate introduced in section 2.3.2 poses several questions relevant to the choice of coefficients in the programming matrices. Effects on cropping intensity and potential for increasing total cropped area can be examined within the model, but yield variations must be specified in advance. The approach taken to this problem is indicated in section 3.6.2, while the importance of yield assumptions in the present study is discussed further in Chapter 6. Other aspects of the 'net contribution' hypothesis, such as quality of land preparation, are less easy to quantify. Similarly, a thorough investigation of the effects of timeliness would require a sophistication of data and model which is not feasible in the present study. Thus, the review of previous studies highlights the weaknesses as well as the strengths of the present modelling approach.

The scope of the current research has purposefully been restricted to exclude consideration of the broader social implications of tractor use. However, the concern displayed by various authors about labour displacement and the worsening of social inequalities suggests that it might be useful to assess the results of the modelling exercise in the context of social, as well as economic, implications. This is attempted in sections 6.2.2 and 6.3.2.

Of the literature reviewed in section 2.4, studies in which linear programming was used (Winkelman 1972, Ahmed 1975, Gotsch 1975, Gotsch and Falcon 1975, Gotsch and Yusuf 1975, Sharma 1976) are of the most direct interest since the method is closest to that of the present research. Useful ideas on the development of the programming matrix have been

obtained from these studies (see sections 3.3.2 and 3.4.3 for further programming references). However, as was mentioned in section 2.4.2, the findings of other authors concerning farmers' decision criteria suggest that great caution should be exercised when attempting to model decision-making behaviour. If it is not feasible to use a comprehensive multi-attribute objective function, then at least the limitations of the alternative, more restrictive objective function must be explicitly noted and borne in mind when discussing the results of the simulations. Theoretical aspects of linear and quadratic programming are discussed in Chapter 3.

Chapter 3

THEORETICAL CONSIDERATIONS

3.1 Introduction

The intention in this chapter is to provide a theoretical review of the techniques adopted in the present study. As explained in Chapter 1, both linear and quadratic programming were used. After a brief introduction to the theory of economic optimisation in section 3.2, linear programming is described and evaluated in section 3.3. A few previous studies are also reviewed. The theory, method and application of quadratic risk programming are then considered in section 3.4.

3.2 The Economics of Optimisation

Much economic production theory is concerned with the maximisation or minimisation of some aspect of the production process, such as profits or costs. The general term 'optimisation' is applicable to this class of problem (Hadley 1962). Tools of differential calculus have been widely applied to deal with problems of unconstrained optimisation, where the aim is simply to determine the 'best' point on the firm's production function. Under conditions of perfect competition, the firm maximises its (assumed) profit objective by producing at the point where marginal value product equals marginal factor cost for all inputs. Depending on the nature of the production function, there may be several points at which this relationship holds. Second order conditions are used to distinguish maxima from minima, while it is usually possible to locate the global maximum within a specified relevant production zone.

In general, firms are subject to a number of resource constraints which may prevent them from attaining their unconstrained optimum. These constraints may be incorporated into the objective function by the use of Lagrangean multipliers. All first partial derivatives of the Lagrangean

function are set to zero and the resulting set of equations is solved simultaneously. In this way, the objective function is optimised subject to the constraints. The values of the Lagrangean multipliers give the shadow values of each constraint, that is, the change in the value of the objective function which would result from a one-unit change in the constraint.

The Lagrangean technique is appropriate when dealing with a single-product firm. However, it becomes cumbersome or unworkable when there are not only multiple inputs and multiple constraints (some of which may be inequalities), but also several alternative productive activities between which resources must be allocated. In this situation, mathematical programming is more suitable.

3.3 Linear Programming

3.3.1 Description and evaluation of the technique

Credit for developing the technique of linear programming is generally given to Dantzig (1951), although earlier advances in linear economic theory, such as game theory (von Neumann 1928) and input-output analysis (Leontief 1936) facilitated his work. Dantzig's critical contribution was the development of a procedure by which a single economic optimum could be identified from among numerous feasible alternatives (Dorfman, Samuelson and Solow 1958).

The general linear programming problem may be stated as the maximisation or minimisation of a linear objective function subject to a set of resource constraints and to non-negativity restrictions on the variables. In the words of Gass (1958, p. 3), it concerns the 'efficient use or allocation of limited resources to meet desired objectives'. In matrix terms, the aim is to optimise a linear objective function

$$\begin{aligned}
 (3.1) \quad & Z = c'x, \\
 & \text{subject to } Ax \leq b, \\
 & x \geq 0,
 \end{aligned}$$

where A = an $m \times n$ matrix of technical coefficients, a_{ij} ;

b = an $m \times 1$ vector of resource stocks and accounting identity

values;
 c = an $n \times 1$ vector of net revenues per unit level of each
 variable; and
 x = an $n \times 1$ vector of activity levels.

The linear programming solution procedure yields the optimum levels of each variable (or activity) as well as the shadow values for the scarce resources. Most computer routines also indicate the sensitivity of the solution to the objective function (c) and right-hand-side (b) coefficients. Sensitivity analysis may be carried further (with some algorithms) by parametrising particular objective function or right-hand-side values. With the aid of the computer, it is also a simple matter to investigate the effect of changes in specific input-output coefficients in the matrix.

Dorfman et al. (1958, p. 4) have described linear programming as 'a flexible and powerful tool of economic analysis'. Programming techniques are readily adaptable to a wide variety of constrained optimisation problems, of which the identification of optimal farm plans is of most relevance to this study.

One early writer (Simpson 1960, p. 306) expressed the view that 'the future of linear programming as regards farm management would seem ... to be firstly as a research method rather than in application to individual farms.' McFarquhar (1961, p. 486) was more optimistic in his assertion that 'it can hardly be contested that linear programming will always give the better technical results from any given data.' Problems of choice between a small number of alternative activities on a farm may be solved by conventional budgeting procedures. However, these procedures are cumbersome if a large number of alternatives exists. Moreover, the budgeting method does not guarantee an optimal farm plan. With linear programming it is possible to consider systematically the effects of different resource allocations in the whole-farm context. Because programming models are generally solved by computer, very large and complex models may be constructed which avoid some of the questionable simplifications of smaller models. However, a number of the assumptions which underlie linear programming may restrict its

application and interpretation. These may be summarised as follows.

(a) The assumption of constant linear input-output relationships is clearly a distortion of reality, since empirically-estimated production functions are rarely (if ever) strictly linear. Moreover, the assumption of linearity violates a basic axiom of economic theory, namely the 'law' of diminishing marginal returns. Non-linear programming techniques, such as separable programming, may be useful where the linearity assumption is critical. Alternatively, '... some curvilinear relationships can be included in an LP model by representing the corresponding processes with activities defining a series of linear segments' (Hardaker and Parton undated, p. 11; see also Duloy and Norton 1975 and Norton and Solis 1983).

(b) Activities and resources are assumed to be additive and divisible. The additivity assumption generally causes no difficulties if the activities are competitively related. Problems may arise if activities are complementary, but additional activities can usually be created to take account of the complementarities. The divisibility assumption may be restrictive in some instances, such as when investigating ownership of 'lumpy' items like draught animals and tractors. In such cases, 'rounding down' the linear programming solution may give a non-optimal result, and so integer programming is more appropriate.

(c) A linear programming model contains a set of single-valued coefficients, and may be criticised on the grounds of inability to incorporate risk and uncertainty. It is possible to use the sensitivity information obtained in the linear programming solutions to assess the impact of coefficient variability on the optimal solution. Alternative modifications of linear programming such as the 'Minimisation of Total Absolute Deviations' (MOTAD; Hazell 1971) and game theory approaches (McInerney 1967, Boussard 1971) are described by Anderson et al. (1977, pp. 202-12). These permit explicit consideration of risk, as does the quadratic risk programming technique used in the current study (see section 3.4). However, additional data are required which may be difficult and time-consuming to acquire (see Chapter 4).

Dorfman et al. (1958) refute the idea that the assumptions of linear programming are so restrictive as to detract significantly from its usefulness. Although admitting that strict realism of the models is unattainable, they contend that 'strict descriptive faithfulness is an unreasonable demand to make of any conceptualisation... What we have a right to ask of a conceptual model is that it seize on the strategic relationships that control the phenomenon it describes and that it thereby permits us to manipulate, i.e., think about, the situation' (Dorfman et al. 1958, p. 9).

In the context of the present study, the assumption of known (riskless) outcomes is considered to be potentially the most restrictive of those listed above. Quadratic risk programming, which avoids this assumption, is discussed in section 3.4. The divisibility assumption is also relevant, but severe computational difficulties may be encountered when attempting to incorporate integer restrictions into a quadratic programming framework. These difficulties are discussed by Mitchell and MacAulay (1984) with reference to the current study.

3.3.2 Previous applications

An exhaustive survey of applications of linear programming to the generation of optimal farm plans is beyond the scope of this study. The discussion here is limited to a few selected references of relevance to developing country agriculture. These studies fall into two broad categories: (a) large-scale regional or sectoral models and (b) small-scale studies of single 'representative' farms or of 'average' farms within a small geographical area.

The first approach was adopted by Egbert and Kim (1975) who modelled the agricultural sector of Portugal, and Stoecker and Khatikarn (1976) who described a national crop model for Thailand. Odero-Ogwel and Clayton (1973) constructed a regional planning program of Kenyan agriculture. They explicitly considered the implications of the aggregation problem, a problem which is encountered in most farming applications of mathematical programming. Since no two farms are identical, a programming model based on data from a single farm is of

limited value to other farms, while a model based on 'average' data cannot be claimed to be strictly relevant to any single farm. These authors attempted to minimise distortions by aggregating according to relative land/labour endowments rather than simply according to farm size.

The second category of programming applications is more common than the first, and is more relevant to the present study. Those in which 'average' farms were constructed and modelled include Ogunfowora (1970) and Wardhani (1976), both of whom were concerned with the identification of optimal plans for new farms in settlement schemes. Ogunfowora used a polyperiod model in his Nigerian study, while Wardhani combined linear programming and Monte Carlo simulation in the context of a transmigration area in Indonesia. Sharma (1977) also used Monte Carlo simulation to supplement his linear programming study of Uttar Pradesh, India. Another study in the same geographical area was by Wills (1972), who used linear programming to estimate the likely effect of the introduction of new technology on future employment and income. De los Reyes (1962) evaluated rice farming systems in the Philippines, while Ahmad (1972) studied a similar topic in Malaysia and noted that partial budgeting could be used to 're-tailor' the modal results to make them relevant to individual farms.

Other applications of linear programming include Johnson (1969) in Rhodesia, Heyer (1972) in Kenya, Low (1974) in Ghana, Hardaker (1975) in Tonga, Burgess (1977) in Western Samoa and Chandra (1981) in Fiji. Stewart (1961) concentrated specifically on 'farm operating capital as a constraint', suggesting that 'in many published examples of linear programming, the capital constraint has not been satisfactorily handled' (p. 463). Andrews and Moore (1976) included nutritional requirements in their recursive programming model of a representative farm-household in the Dominican Republic. Calkins (1981) described the integration of 'income-maximisation and least-cost diet models' (p. 247) within a single linear programming framework. The optimal farm plans for the representative Nepalese farmers were thus the most nutritious which could be achieved within the framework of income maximisation.

The focus of the current study is on the introduction of new technology. This has been a theme of several previous programming studies, including some of those which have already been mentioned (e.g. de los Reyes 1962, Wills 1972). The economics of the Green Revolution in the Punjab were modelled in a few of the studies reviewed in Chapter 2. Variants on a basic programming model were used to investigate the importance of irrigation and animal power constraints in traditional agriculture (Gotsch 1975) and the introduction of tubewells, high-yielding varieties (Gotsch and Falcon 1975) and tractors (Ahmed 1975). Gotsch and Yusuf (1975) then used a mixed integer programming model to determine optimal equipment packages for farms in the study area.

Barlow, Jayasuriya and Price (1983) described a study of technological innovation in the Philippines. Ten farm models were constructed from detailed case-study data and used to assess the impact of new technologies at the household level. District-level implications were then drawn with the aid of supplementary survey data. The current research has much in common with their approach.

Specification of a programming model which accurately reflects the important characteristics of the farm/household system is not a simple task. Musgrave and Bird (1966), Rickards and McCarthy (1966), MacAulay (1969), Wrigley and Sturgess (1969), Monypenny (1975) and Singh and Day (1975) all presented their full programming matrices. These proved useful for model specification in the current study.

3.4 Quadratic Risk Programming

Much of the theoretical discussion in section 3.3.1 is equally relevant to quadratic programming, and so will not be repeated in this section. The crucial difference between linear and quadratic programming is that it is possible with the latter to consider the effect of attitudes towards risk by specifying a utility function as the objective function in the model. The meaning and importance of 'risk' and 'utility' are discussed in section 3.4.1, and alternative practical methods of incorporating them into decision analysis are mentioned. The

method chosen for the current study is quadratic risk programming. Theoretical and technical aspects of this technique are addressed in section 3.4.2. A few previous applications are reviewed in section 3.4.3.

3.4.1 Risk and utility

According to Roumasset (1979, p. 4), 'uncertainty is a state of mind in which the individual perceives alternative outcomes to a particular action. Risk, on the other hand, has to do with the degree of uncertainty in a given situation.' Dillon and Hardaker (1980, p. 134) define risk simply as 'a situation with uncertain consequences.' Narrower definitions have been suggested by those who wish to measure attitudes towards risk. For this purpose, risk has been defined as 'one or another measure of the dispersion of possible outcomes, for example, as variance' (in quadratic risk programming), or as 'the probability that returns to a given decision will fall below some critical "disaster" level' (in focus-loss programming; Boussard and Petit 1967), or as 'what risk averters will pay to avoid' (Roumasset 1979, p. 4). Roumasset's conclusion is that 'risk should be defined in order to maximise its usefulness as a concept.' It is therefore essential that 'researchers should specify which definitions they are using when they report their own work' (1979, p. 5).

The definition of 'utility' is closely allied to the definition of 'risk' in many respects. While the term 'utility' may itself be simply a synonym for 'benefit' or 'pleasure', the 'expected utility hypothesis' is a principal postulate of decision analysis under uncertainty (see Anderson et al. 1977, ch. 4). The essence of utility theory as conceived by Bernoulli (1738) was that 'an extra dollar is worth more to a poor man than to a rich man' (Anderson et al. 1977, p. 66). In other words, the marginal utility of money is not constant. It follows that it may be misleading to rank decision alternatives simply on the basis of expected money values (EMV). The hypothesis was formalised by von Neumann and Morgenstern (1947), as follows (Anderson 1979, p. 40):

For a decision maker whose preferences are consistent with the axioms of ordering, continuity and independence, a utility function, U , exists which associates a real number with any confronted risky

prospect such that if a prospect (probability distribution) G is preferred to F then $U(G) > U(F)$ and, conversely, if $U(G) > U(F)$ then G is preferred to F . Further, the utility of a prospect G is its expected utility, $U(G) = EU(G)$.

The mathematical form which such a utility function is assumed to take is largely a matter of theoretical acceptability and analytical convenience. For the purposes of quadratic risk programming, expected utility must be expressed in terms of the expected mean and variance of activity returns. There are three general cases in which the mean and variance give exact representations of utility functions. These are:

- (a) where a general utility function is approximated by a cubic function and total net revenue is assumed to be symmetrically distributed ($M_3 = 0$);
- (b) where a general utility function is approximated by a quadratic function; and
- (c) where utility is assumed to be of negative exponential functional form and the distribution of total net revenues is assumed to be normal.

There has been much debate in the literature about the acceptability of ignoring terms beyond the second moment of a Taylor series expansion, as is the case where symmetrical cubic or quadratic functions are used (Tobin 1969, Tsiang 1972, Porter 1974, Bierwag 1974, Borch 1974, Levy 1974, Tsiang 1974, Parton 1984). Other criticisms of simple polynomial utility functions are that they 'are not everywhere monotonically increasing' and that they 'fail to meet the intuitive requirement of decreasing risk aversion with increasing wealth' (Anderson et al. 1977, pp. 93-4). These difficulties, once recognised, need not be unduly restrictive. As Anderson et al. (1977, p. 94) state, no-one 'with his wits about him [would] use a polynomial approximation outside the range where it is monotonically increasing.'

Negative exponential utility functions, on the other hand, have constant risk aversion along their entire range. For practical purposes, this characteristic may be assumed to be a reasonable approximation within the range of interest. Freund (1956, p. 255) proved that when the expected value of utility in a negative exponential function is taken over the normal distribution, the exact result is a quadratic function. Thus, the maximum of the exponential function

$$(3.2) \quad E(u) = \int_{-\infty}^{\infty} (1 - e^{-Lr}) e^{-(r-m)^2/2V} dr,$$

occurs at the same point as the maximum of the quadratic function

$$(3.3) \quad E(u^*) = m - 0.5LV,$$

where $E(u)$ = expected utility;

L = a constant risk aversion coefficient;

r = net revenue;

m = mean net revenue; and

V = variance of net revenues.

Acceptance of the postulate of constant risk aversion greatly simplifies the procedure for elicitation of utility functions (see section 4.4.5). The negative exponential functional form was consequently adopted in the present study.

The rationale for summarising utility in terms of the mean and variance of activity net returns has been questioned by Parton (1984). He focussed on the work of Selby and Hendrix (1976) who carried out anthropological research in Mexico. They interviewed individual respondents in great depth in order to specify a set of 'culturally defined goals' to incorporate into a linear programming objective function. Five major components of a Zapotec Indian utility function were identified: 'leisure', 'personal betterment', 'life style', 'security' and 'self-respect and the respect of others' (Selby and Hendrix 1976, p. 224). These authors cautioned other researchers that 'understanding how people operate in a cultural milieu requires more than superficial examination of their stated priorities' (p. 243). While it

may be impractical to expect economists to conduct intensive anthropological fieldwork, it should be acknowledged that an over-simplified view of the goals of their subjects may considerably weaken the value of their findings. In particular, it must be recognised that recommendations for the maximisation of utility may be relevant only to the extent that the farmers' 'actual' utility functions are represented.

In the current study, quadratic risk programming models were used to investigate the importance to farmers of the variability of activity returns. Other factors which appeared to contribute to farmers' utility included subsistence consumption and the availability of cash for education, religious ceremonies and general household expenses. These requirements were included in the models as constraints. The maximisation of mean and minimisation of variance were therefore achieved in conjunction with the satisfaction of other goals (see Chapter 5).

3.4.2 The quadratic risk programming technique

A quadratic risk programming problem may take one of two forms. If the decision-maker's utility function is known and satisfies one of the conditions listed in section 3.4.1, it may be incorporated directly into the objective function. Equation (3.3) may be rewritten in matrix notation as the objective function of a programming formulation, as follows:

$$(3.4) \quad \begin{aligned} \text{Max EU} &= p'x - 0.5L x'Qx, \\ \text{subject to } Ax &\leq b, \\ x &\geq 0, \end{aligned}$$

where EU = expected utility;

p = a vector of mean activity net revenues;

L = the Pratt coefficient of risk aversion (Pratt 1964);

Q = a variance-covariance matrix for activity net revenues;

A = a matrix of technical coefficients;

b = a vector of resource stocks and accounting identities; and

x = a vector of activity levels.

The solution to this problem is a single utility-maximising plan.

Alternatively, and particularly when the decision maker's utility function is unknown, the problem can be stated as the minimisation of variance subject to a parametric minimum expected revenue constraint (Anderson, Dillon and Hardaker 1977, pp. 197-8). When solved with the RAND QP360 computer algorithm (Cutler and Pass 1971), the problem takes the form:

$$(3.5) \quad \begin{aligned} \text{Min } EU &= -Wp'x + x'Qx, \\ \text{subject to } Ax &\leq b, \\ x &\geq 0, \end{aligned}$$

where EU, p, Q, A, b and x are defined as in equation (3.4), and W is a weighting factor which is varied parametrically to give change-of-basis solutions. Graphing these solutions gives the mean-variance (E,V) frontier or efficient set. All plans lying on the E,V frontier have minimum variance for each given level of mean net revenue, and are therefore efficient for any risk-averse farmer who seeks to maximise net returns. However, no single plan can be identified as optimal unless the farmer's attitude towards risk (variance) is known. If the farmer's utility function is available, iso-utility curves can be superimposed on the graph of the E,V frontier. The point of tangency between the E,V frontier and the highest indifference curve is the utility-maximising position for that individual farmer. Otherwise, the range of plausible solutions may be restricted by making an assumption as to the degree of risk aversion which is likely to exist. This approach is followed in the current study, as discussed in Chapter 6.

3.4.3 Previous studies

The extent to which risk attitudes influence behaviour has been the main concern in a number of studies comparing the hypotheses of profit-maximisation and (mean-variance) utility maximisation. Lin, Dean and Moore (1974) developed optimal plans for six Californian farms under each assumption, and concluded that the utility-maximising plans were closer to actual and planned patterns than were the profit-maximising

plans. Similarly, Wiens (1976, p. 633-4) claimed that 'the results of risk neutral linear programming solutions are distinctly contrafactual [whereas] by contrast, the risk aversion model accords quite well with the average behavior of the sampled [Chinese] peasants.' Camm (1962), Officer and Halter (1968), Capstick (1973) and Bartholomaeus and Hardaker (1981) also found that quadratic risk programming was superior to riskless linear programming.

Hardaker and Ghodake (undated) extrapolated Binswanger's (1981) experimental measurements of risk aversion so as to develop quadratic risk programming models of small, medium and large farms in semi-arid tropical India. They found that the predicted risk-averse plans for small farms accorded well with actual cropping patterns, but that 'risk aversion was not important in determining land use on the medium and large farms.' This was 'presumably because ... a diversified cropping pattern is necessary on these farms to satisfy the resource constraints' (Hardaker and Ghodake undated, p. 17).

Bond and Wonder (1980) also doubted the significance of risk aversion. Their survey of risk attitudes among Australian farmers revealed that risk aversion was the most common attitude, but the degree of such aversion was generally slight. Consequently, 'farmers may in aggregate, pursue production and investment strategies which are not very different from risk neutral behaviour' (Bond and Wonder 1980, p. 32).

In a similar vein, Rosegrant (1978) found that the extent to which risk aversion in Central Luzon reduced 'mean input levels, yields, and income relative to risk neutrality' increased only slightly as the severity of the risk aversion assumption was increased. Therefore, 'risk aversion ... does not represent a severe barrier to increasing yields and farmer income' (p. 121). Roumasset (1973) came to a similar conclusion with respect to patterns of fertiliser use on Filipino farms, finding the risk aversion model to have little predictive value.

One of the hypotheses under investigation in the current study (Hypothesis 2, section 1.4) is designed to focus attention on the issues raised in this section. Evaluation of the hypothesis involves an

examination of the importance of risk attitudes in the context of optimal patterns of tractor and animal use in the study area (see section 6.4).

3.5 Concluding Remarks

The techniques of economic analysis used in the current study have been discussed in this chapter. Linear programming is a powerful tool, but its shortcomings must be recognised. The attitude of farmers towards risk may be a significant determinant of their choice between alternative technologies. Quadratic risk programming models were formulated in an attempt to investigate this aspect of farmer decision-making. The objective function in quadratic risk programming is the maximisation of expected utility, where utility is defined in terms of the mean and variance of returns. Criticisms of this definition have been presented in section 3.4.1.

Finally, it should be noted that the accuracy of the results of programming applications (whether linear or quadratic) is entirely dependent on the realism of the initial model formulation and the accuracy of the data used. The first of these aspects is dealt with in Chapter 5, while the problem of data collection is addressed in Chapter 4.

Chapter 4

DATA

4.1 Introduction

The study area, sample selection and details of data requirements and fieldwork are described in this chapter. As noted in the conclusion to Chapter 3, the value of modelling exercises such as the one reported in this dissertation is strongly dependent on the reliability of the data used. On small farms in developing countries, detailed farm records are seldom kept. Consequently, the researcher generally has to rely on farmers' recall or rough estimates, or on aggregated regional or national statistics. The difficulties may be even more pronounced when farmers are asked to respond to hypothetical situations which require a degree of introspection to which they are not accustomed. Such may be the case when quadratic risk programming is used, since there is a need to elicit (a) subjective probability (frequency) distributions for activity net returns, and (b) utility functions. Elicitation techniques and the practical difficulties of using them are discussed in sections 4.4.4 and 4.4.5. Implications for the present study are explained in section 4.5.

4.2 The Study Area

Luwu district (kabupaten) is situated in the north east of the Indonesian province of South Sulawesi (see Figure 4.1). It covers an area of just over 25 000 square kilometres and had an estimated population of 520 000 at the end of 1981 (Checchi/DMJM 1982). The labour force in Luwu in 1980 was estimated at 163 900 males and 168 600 females (Checchi/DMJM 1982, p. 32). A 1975 survey reported by Checchi and Company (1983, p. 19) revealed that on-farm use of family labour averaged between 10 and 27 man-days per month in three sample areas. Off-farm employment accounted for a further 52 man-days per year, while an average of 20 man-days per year were spent on gotong royong (mutual exchange or

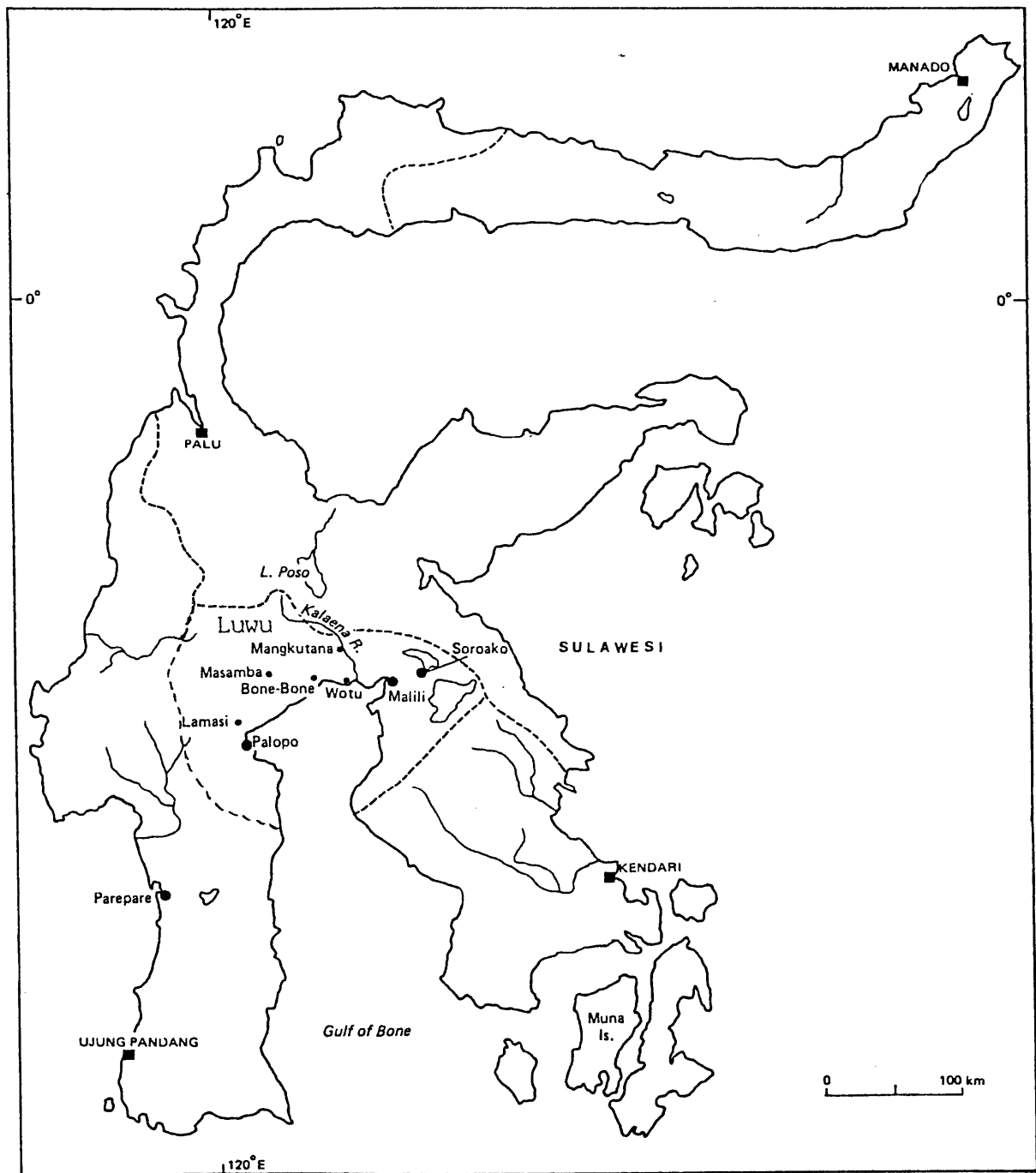


Figure 4.1 Location of Luwu District.

Source: adapted from Hardjono (1977, p. 80).

community labour) activities.

Agriculture is the predominant sector in the economy, although much of the land remains uncultivated (Checchi and Company, 1983). Approximately 50 000 ha of upland and lowland rice were harvested in 1982 (Dinas Pertanian 1983), while other crops included maize (4000 ha), cassava (1000 ha), sweet potatoes (600 ha), soybeans (550 ha) and peanuts (400 ha). Actual land use patterns depend to some extent on the availability of irrigation for sawah (lowland rice field) cultivation. A study by the provincial university (Universitas Hasanuddin 1981) found that rice production was the major income-earning activity in fully irrigated areas, whereas dryland crops and off-farm work made a substantial contribution in unirrigated areas. Data on crop production and rainfall are presented in Appendix A.

About 73.8 per cent of sawah in Luwu were served by some form of irrigation system by 1980, but only 6.1 per cent, or 3266 ha, had 'fully controlled irrigation to the tertiary level' (Checchi and Company 1983, p. 15). Such engineered irrigation was available in just two of the sixteen kecamatan (sub-districts) in Luwu, namely, Bone-Bone and Mangkutana. Construction and rehabilitation of irrigation systems in North Luwu has been a major concern of the Luwu Area and Transmigration Development Project ('Project Luwu') initiated jointly by USAID and the Government of Indonesia in 1974. By the end of 1983, the intention was to have 13 100 ha of fully controlled irrigation in North Luwu (Checchi and Company 1983).

The village of Sidomukti, which is located in kecamatan Bone-Bone (see Figure 4.2), was chosen for the present study. It was established in 1938 under the Dutch kolonisasi scheme as a settlement for East Javanese migrants. The current population is about 5000, while the area covered by the village and its surrounding irrigated ricelands is about 1000 ha. The effect of Project Luwu has been particularly strong in the Bone-Bone district, with the upgrading of the trunk road which passes through the area and the extension of the irrigation system based on the Bone-Bone and Kalaena Rivers to serve an area of 8480 ha (Checchi and Company 1983). Bone-Bone has also been a centre for other Project Luwu

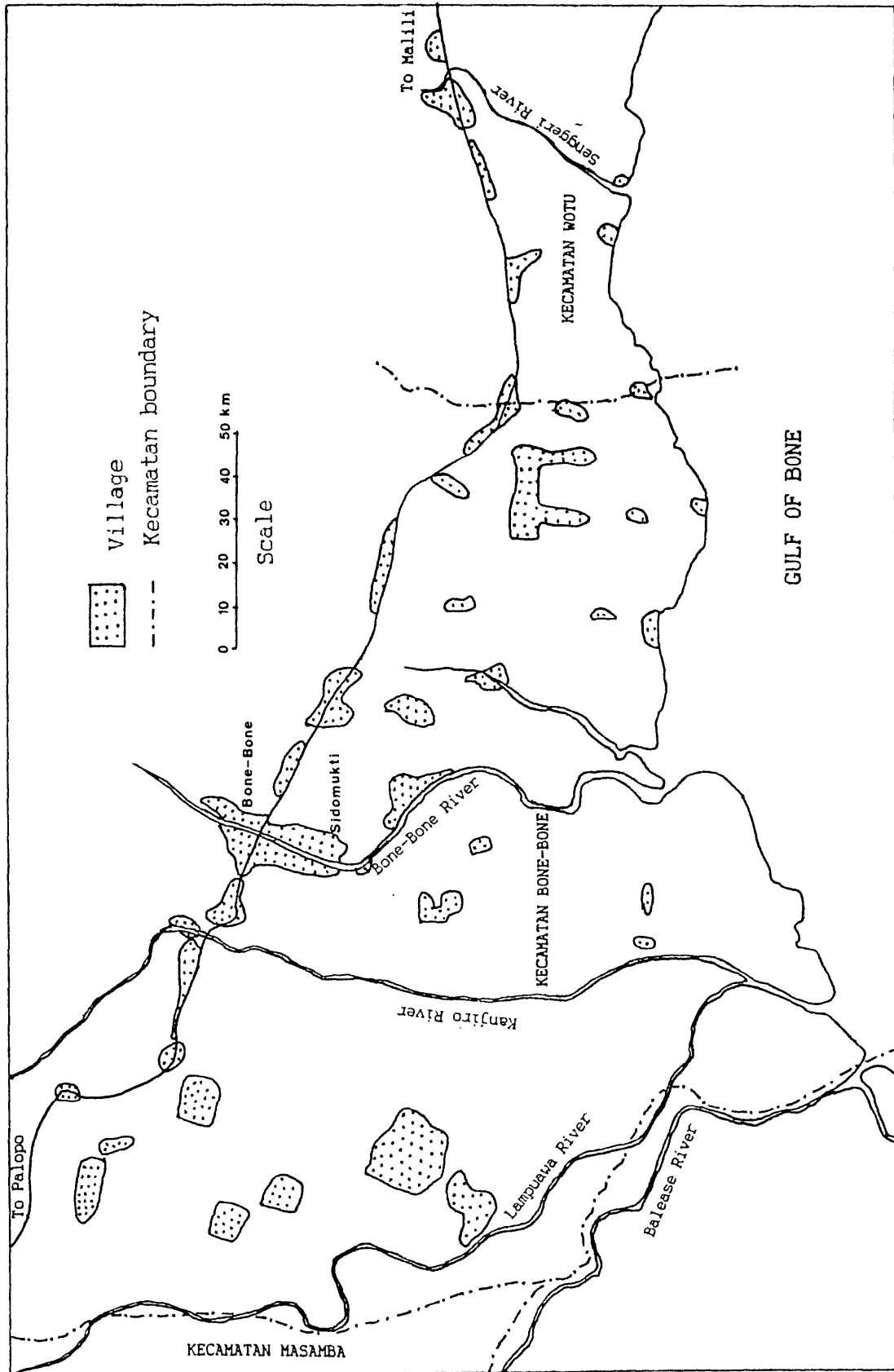


Figure 4.2 Location of Sidomukti Village.

Source: BAPPEDA (undated).

activities, such as a vigorous extension and farmer training program conducted by the Rural Extension Centre and a tractor hire service provided by the Farm Cooperative Centre. Sidomukti, which is situated less than 5 km from these centres, has been particularly well served. It is one of the first villages to have had access to four-wheeled mini-tractors from the Farm Cooperative Centre. Twelve tractors are now available from this source, while an additional five are owned by individuals or groups in Sidomukti itself.

The relatively advanced stage of mechanisation in Sidomukti was one reason for selecting this village for fieldwork. Another important reason was that Sidomukti was sampled in surveys administered by Hasanuddin University in 1980 and 1982 (Universitas Hasanuddin 1981, 1983). Moreover, at least some of the respondents in a recent study of two and four-wheeled tractor use were from Sidomukti (Luwu Area Transmigration and Development Project and International Rice Research Institute 1983). Consequently, background information was available both from published reports and from the original Hasanuddin University questionnaires completed in 1982 (Universitas Hasanuddin 1982). Such information was valuable for both questionnaire design and sample selection.

4.3 Sample Selection

Three possibilities were considered for the selection of a sample for the present research. These were (a) statistical sampling, (b) construction of 'average' farms based mainly on secondary data and (c) the case study approach. Use of the first method would have minimised bias in sample selection and permitted the statistical testing of hypotheses. However, it was not feasible to conduct a large-scale survey given the time available and the length and complexity of the questionnaire. The second method might have reduced the burden of primary data collection, but undue reliance would have been placed on the existence and accuracy of secondary data. Aggregation bias, mentioned in section 3.3.2, might also have caused difficulties. The case study approach therefore appeared to be the most appropriate for the current research. This involved conducting detailed interviews with a small

number of farmers and developing separate programming models for each farm. Comparisons could then be made between farms in various categories of tractor and animal use. Causal factors in farmer decision-making could be identified and the results extrapolated to the wider population of the study area.

Once Sidomukti had been selected as the sample village, data were obtained from the Farm Cooperative Centre in Bone-Bone concerning the identity of all Sidomukti farmers who hired a tractor during the January/February 1983 land preparation season. The date of the tractor use and the area ploughed were also noted. Eighteen tractor users were selected for preliminary interview. According to the available records, these farmers were fairly representative of the tractor-using population. Characteristics of the sample and the population are summarised in Appendix B. The 1982 university questionnaires (Universitas Hasanuddin 1982) were then examined and a further six farmers were selected as representatives of the non-tractor using population (see Appendix B).

A preliminary survey of the farmers mentioned above was conducted to ascertain levels of animal and tractor use during the previous two seasons. Other questions covered land ownership, family size and willingness to respond to the detailed questionnaire. Some of the farmers initially selected for this survey were unavailable due to illness or absence, and so a total of 20 farmers were interviewed. Responses are tabulated in Appendix B. Three categories of tractor and animal use were identified on the basis of the information obtained in the preliminary survey. Two farmers representative of each category were then selected as sample farmers. The categories and the codes assigned to the sample farmers were as follows:

- (a) used animals only, dry season 1982 and wet season 1983 (farmers AA1 and AA2);
- (b) hired a tractor, dry season 1982 and wet season 1983 (farmers TT1 and TT2);

- (c) hired a tractor for just part of the total land cultivated (farmer TA1) or for just one of the two seasons under investigation (farmer TA2).

Although farmers in the last category may be considered to be exceptions rather than 'representative' of the wider population, their recent experience of both types of land preparation made them especially interesting for this study.

Two tractor owners were also interviewed. One of these participated in a lengthy pre-test of the questionnaire. He owned a tractor jointly with five brothers, while the second respondent was an individual owner. Programming models were not constructed for the two tractor owners, mainly because the initial purpose of the study was to examine tractor use rather than ownership. Considerable extra data and time would have been required to develop tractor-owning options for each farmer. Nevertheless, characteristics of all eight farmers are shown in Table 4.1 for comparative purposes.

4.4 Data Collection

Data were collected during a three-month visit to South Sulawesi. Approximately half of that time was spent in Luwu collecting historical and survey data, while the remainder was spent in the provincial capital of Ujung Pandang, preparing for the fieldwork.

4.4.1 Data requirements for quadratic programming

For each of the sample farms in this study, the following data were required:

- (a) farm and household budget information, including farm resources, input levels, costs, production levels, consumption and sales. Basic linear programming models could then be developed;
- (b) subjective probability distributions of the value of each crop (where 'tractorised rice production' was considered a separate crop from 'non-tractorised rice production'). In addition, for each pair of crops grown, a probability distribution for crop

Table 4.1
Characteristics of Sample Farmers

	Farmer ^a							
	AA1	AA2	TA1	TA2	TT1	TT2	T01	T02
Age	55	50	47	54	39	34	41	38
Education (years) (Literacy)	6	6	9	6	8	8	3	12
Household size	4	6	7	5	5	5	8	5
Sawah cropped (ha)	1.00	1.00	1.75	1.00	1.00	1.00	2.00	1.50
Dryland cropped (ha)	0.125	0.375	0.08	0.25	0.10	0.75	0.375	1.80
Cattle owned	6	5	8	4	0	0	6	6

^a Farmers AA1 and AA2 used animals only; TA1 hired a tractor for only part of his land; TA2 hired a tractor for dry season 1982 but not for wet season 1983; TT1 and TT2 both hired a tractor for all their land in both seasons; and T01 and T02 are tractor owners.

value should have been elicited for one, conditional on the value of the other being fixed at a particular level (see section 4.4.4). With these data, the variance-covariance matrix of activity net revenues could be calculated. The parametric method of quadratic programming could then be used to trace out E,V frontiers, as explained in section 3.4.2;

- (c) farmers' utility functions for the value of net farm output. These would permit the identification of a single optimum on each farmer's E,V frontier;
- (d) any other available data on (i) levels of tractor, animal and human labour supply and use in the study area, and (ii) yield and price variability for the various cropping and livestock activities. The first category of data would assist in the specification of constraint levels, while the second category could be used instead of subjective data for the estimation of variance-covariance matrices.

4.4.2 Historical data

The data described in section (d) above were collected from regional branches of the national planning office (BAPPEDA) and the Statistics Office (Kantor Statistik) in Palopo, the capital of kabupaten Luwu, and from the Farm Cooperative Centre in Bone-Bone. Time series data for the production of rice and other crops were obtained for the 1974-82 period for each kabupaten in Luwu, while monthly price data were also collected. Additional sources of historical information were publications by Makaliwe (1969), Goldman (1974), Pitt (1977), Anon (1979), Kantor Sensus (1979), Biro Pusat Statistik (1980), Checchi/DMJM (1982) and Checchi and Company (1983). Relevant data are summarised in Appendix A.

4.4.3 Questionnaire design

The questionnaire administered to the eight sample farmers comprised sections on rice, other crops, livestock, income and 'utility', as well as a background section on household size and land ownership. The complete English translation of the questionnaire is given in Appendix C, while responses are summarised in Appendix D. In the crop and livestock sections, farmers were asked for details of purchased inputs, human labour, animal and tractor use and disposal of the produce (e.g. consumption, storage, sale, milling). In addition, probability distributions for yields of tractorised and non-tractorised rice were elicited, as described in section 4.4.4. Asset ownership, off-farm work, credit use and monthly cash flow data were recorded in the income section. The questions dealing with utility are discussed in section 4.4.5.

The eight sample farmers were interviewed with the aid of an interpreter over a period of ten days in September 1983. The entire questionnaire required a minimum of five hours per farmer for completion, generally spread over two or three visits. The farmers were totally cooperative, even enthusiastic, throughout this process and willingly provided the budget and resource use details requested. At all times they appeared to respond to the best of their ability, subject to the reliability of their memories. The elicitation of subjective probability distributions and utility functions proved to be the most difficult tasks, as discussed in sections 4.4.4 and 4.4.5 below.

4.4.4 Elicitation of subjective probability distributions

The mean and variance of the value of an activity, and covariances between activity values, could have been calculated from historical data or from subjective data elicited from the respondents. According to Anderson et al. (1977, p. 18), 'subjective probability is the only valid concept for decision making' since it is the beliefs of the decision maker, rather than historical 'fact', which ultimately determine his choices.

Several methods have been devised for eliciting subjective probability distributions (Anderson et al. 1977, pp. 21-6). The judgemental fractile method is convenient when the cumulative distribution function (CDF) is to be determined directly. The method was used in the present study with reference to expected rice yields with and without tractor use (see Appendix C, section II(f) for questioning procedure). For the purposes of quadratic programming it was necessary to specify distributions in terms of value or revenue. However, such an approach was not practical when interviewing semi-subsistence farmers who were not accustomed to thinking about total crop value. Historical price data were therefore used to supplement the subjective yield data, as explained in section 5.3.

It was assumed from the outset that the yield distributions were approximately normal. The effect was to greatly simplify the questioning procedure, since only two fractile values were required in order to estimate mean and variance.

Crops other than rice were not included in the probability elicitation. The sample farmers would not consider hiring a tractor for dryland preparation, and so the non-rice crops were of minor importance in this study. Dryland crops such as maize and peanuts were grown on two of the farms modelled. Yield variances of these crops were estimated from historical data so as to avoid making additional demands on the respondents. Tree crops were not included in the models.

All the sample farmers appeared to achieve a good understanding of the probability elicitation procedure. The recommendations of Anderson et al. (1977, p. 24) were followed so as to avoid biases of anchoring and representativeness (Tversky and Kahnemann 1975). However, one farmer (AA2) refused to contemplate the possibility of low yields. He believed such thoughts would 'anger God', who might then punish him by restricting his future yields to low levels. In consequence, the variance estimates for this farmer's yields had to be based solely on his statement of the lowest and highest yields he had personally experienced.

The attempt to elicit covariance data (conditional probability distributions) from the farmers was not successful. At best, farmers could give a single expected value for one yield, conditional on the other yield being fixed at some specified level. This was not sufficient for analytical purposes. Part of the difficulty may have been that the interpreter himself was not able to understand fully the concept of conditional probability.

The method used to combine the subjective yield data with historical data is explained in section 5.3. The accuracy of the resulting 'subjective' variance-covariance matrices is questionable. Alternative matrices were therefore calculated from purely historical data. These were not necessarily more valid than the subjective matrices, but they proved useful for sensitivity purposes (see Chapter 6).

4.4.5 Elicitation of utility functions

There are three techniques commonly used for the elicitation of utility functions. These are the von Neumann-Morgenstern method (von Neumann and Morgenstern 1947), the modified von Neumann-Morgenstern or Equally Likely Certainty Equivalent (ELCE) method (Anderson et al. 1977, pp. 70-5) and the Ramsey or Equally Likely but Risky Outcomes (ELRO) method (Ramsey 1964, Anderson et al. 1977 pp. 75-6). In each case, the expected utilities of alternative acts are equated with reference to Bernoulli's Principle, in order to specify points on a utility scale or function. Each procedure is outlined briefly below.

With the von Neumann-Morgenstern approach, subjects are asked to choose between:

- (a) taking a risk in which they may score a high return with probability p or a low return with probability $(1-p)$; or
- (b) accepting an intermediate sum with certainty (no risk).

The probability associated with the risky prospect in option (a) is varied in successive iterations, until the respondent is indifferent (unable to choose) between alternatives (a) and (b). The main criticism

of this approach is that most people have difficulty 'in mentally grappling with probabilities other than those involving only a single decimal digit.' Moreover, subjects may exhibit 'probability bias', that is, 'preferences for particular probability values (as "favourite numbers" as it were)' (Anderson et al. 1977, p. 69).

These shortcomings are avoided by using the modified von Neumann-Morgenstern or ELCE method. The choice between 'lottery' and 'certainty' remains as above, but the probabilities associated with the lottery are fixed at the 'ethically neutral' level of 0.5 (Anderson et al. 1977, p. 70). Instead, the value of the certainty is varied until indifference is reached.

Complete elicitation of an individual's utility function by the ELCE method requires the identification of certainty equivalents for several lotteries within the relevant range of income. This is because the degree of risk aversion may depend on the income level to which the question pertains. However, it was explained in section 3.4.1 that utility functions in the present study were assumed to be of negative exponential form. Such functions have constant risk aversion over their entire range. Consequently, elicitation of a single certainty equivalent is sufficient to provide the Pratt coefficient of absolute risk aversion (Pratt 1964) which is required for quadratic risk programming.

One criticism of the ELCE method is that a strong attitude towards gambling per se may influence the respondent's stated preferences, so that his 'true' utility function is distorted. The Ramsey or ELRO approach theoretically alleviates this problem (Anderson et al. 1977, pp. 75-6). In this procedure, the subject is given a choice between two different 50-50 lotteries instead of between a lottery and a certainty as with ELCE. One of the four outcomes is then varied until the farmer is indifferent between the two lotteries. Again, elicitation of the complete utility function requires several such questions, but one is sufficient once constant risk aversion is assumed.

Both ELCE and ELRO elicitation procedures were attempted with the eight case-study farmers. A simple 'coin game' was used first to illustrate the choices involved (see Appendix C, section V(e), for interview schedule). The ELCE method was thought to be conceptually simpler and therefore more likely to be grasped by the farmers. However, three of the farmers objected strongly to the idea of gambling. Another three did not appear to refuse the gamble per se, but they showed extreme risk aversion, for instance preferring a certainty of Rp. 850 005 to a lottery between Rp. 850 000 and Rp. 1 500 000. One farmer (a tractor owner) was an extreme risk preferrer, opting for the lottery between Rp. 2 million and Rp. 2.8 million rather than a certainty of Rp. 2.799995 million. The remaining farmer appeared to be perfectly risk neutral.

Such extreme results conflict with the findings of other researchers (for example Dillon and Scandizzo 1978, Bartholomaeus and Hardaker 1981; Hamal 1982). They also lend support to Roumasset's (1976, p. 30) comment that 'the lottery approach is subject to substantial bias'. It was hoped that some of this bias would be avoided by using the ELRO method. In fact, the ELRO results confirmed the ELCE results in the five cases where attitude to gambling was not extreme. Moreover, contrary to the claim made by Anderson et al. (1977, p. 75), the difficulties caused by aversion to gambling were not overcome by using ELRO. Respondents who were strongly opposed to gambling would not accept a procedure in which the two alternatives offered to them both involved gambling. The three farmers who objected to the ELCE games objected no less strongly to the ELRO games. One of these farmers finally agreed to participate in ELRO for reasons of goodwill towards the interviewer. However, his comments indicated that his responses were determined by his perceptions of how a gambler would respond, rather than by his own preferences.

It is possible that a greater degree of success could have been achieved in the elicitation of utility functions if more time had been available for discussion with the farmers. However, it appeared to be unwise to make further demands on their patience and hospitality by prolonging the already lengthy interview sessions. An additional difficulty was that it was necessary to conduct the interviews through an

interpreter who had had no previous training in techniques of decision analysis. The scope for detailed discussions was consequently limited.

The utility data obtained from the eight sample farmers was generally inadequate for inclusion in the quadratic programming models. It was therefore not possible to identify a single optimum on each E,V frontier. Nevertheless, the E,V frontiers themselves could be specified and a range of theoretically plausible optima suggested, as illustrated in Chapter 6.

4.5 Concluding Remarks

The main focus of this chapter has been on methods of data collection for quadratic risk programming. Empirical difficulties exist in the elicitation of both subjective probability distributions and utility functions. These difficulties need not detract significantly from the value of quadratic risk programming applications. However, limitations must be acknowledged and adequate sensitivity analyses conducted. In the current study, utility analysis was not undertaken because of the poor quality of the data. In addition, historical variance-covariance matrices were calculated as alternatives to the subjective matrices. This avoided placing undue reliance on a single set of estimates. The following chapter deals with the development of the models for this study, while the results are discussed in Chapter 6.

Chapter 5

MODEL STRUCTURE AND ESTIMATION

5.1 Introduction

The models developed for the present study are discussed in this chapter. The first stage involved building a linear programming model for each farmer which reflected, as accurately as possible, the choices open to him. These models are discussed in section 5.2. Constraint levels were initially determined with reference to farmers' actual resource use in 1982-83. Sensitivity analyses were then conducted to investigate the effect of changes in resource availability.

Following verification and validation of the linear programming models, the next stage was to estimate variance-covariance matrices for the crop and livestock production activities. This proved to be an extremely time-consuming task because of the difficulties described in section 5.3. Once these difficulties had been resolved, the parametric quadratic risk programming procedure (equation 3.5) was used to derive mean-variance (E,V) frontiers. Some concluding remarks are offered in section 5.4.

5.2 Structure of Linear Programming Models

As explained in section 5.1, linear programming models were developed prior to the formulation of quadratic risk programming models. This was in order to ensure that any errors in the basic model structure were corrected before the variance-covariance matrices were incorporated. The linear programs were designed such that no alteration beyond the simple inclusion of variances and covariances was needed for them to function as quadratic programs. The models for each of the six sample farms had a similar structure, with specific activities being added or deleted to match individual circumstances. The full linear programming

matrix for one of the six farmers is presented in Appendix E.

5.2.1 Objective function, activities and constraints

The objective function for the linear models was the maximisation of the expected net value of farm/household production.¹ 'Net value' was chosen in preference to the more common 'net revenue' because of the semi-subsistence nature of the farms. All produce was thus given equal value in the objective function regardless of whether it was sold or consumed.

The basic structure of the programming models is shown in Table 5.1. There were several distinct sections, including rice, poultry, cattle, tractor hire, labour and cash. Six two-month periods were specified for cash flows and hence for most of the activities which contribute to the cash supply. The crop production activities were seasonal. Crops other than rice were excluded in four of the six cases, since these farms had only a small number of fruit trees which have little impact on the farm-household economy. A maize section was added for farmer TA2 and a peanut section for farmer AA2.

A flowchart of the activities and constraints associated with rice production is shown in Figure 5.1. The four rice production activities (tractorised and non-tractorised, in wet and dry seasons) required inputs of land, human labour for various purposes, cattle labour, cash and (optionally) tractor power. The objective function values were the costs of inputs not otherwise included in the model, such as seeds and chemicals. Another set of four activities was specified for the purpose of valuing the entire rice output. These valuation activities were unnecessary in the linear programming model, since rice could be valued at the point of sale or consumption. However, for quadratic programming it was necessary to design activities such that the mean and variance of crop value (price x quantity) enter into the objective function. Rice was therefore given a value per hectare of output, while its contribution to cash supply remained dependent on whether the output was sold or

¹ The problem was restated as a minimisation problem for the purposes of solution with the Rand QP360 algorithm (Cutler and Pass 1971).

Table 5.1
Structure of the Programming Models^a

	Rice (39)	Poultry (17)	Cattle (10)	Tractor (2)	Labour (55)	Cash (13)	RHS
OBJ	x	x	x	x	x	x	
Land (2)	x						x
Rice (19)	x						x
Poultry (6)		x					x
Cattle (5)	x		x				x
Tractor (2)	x			x			x
Labour (41)	x		x		x		x
Cash (8)	x	x	x	x	x	x	x

^a 'x' indicates the presence of non-zero coefficients.

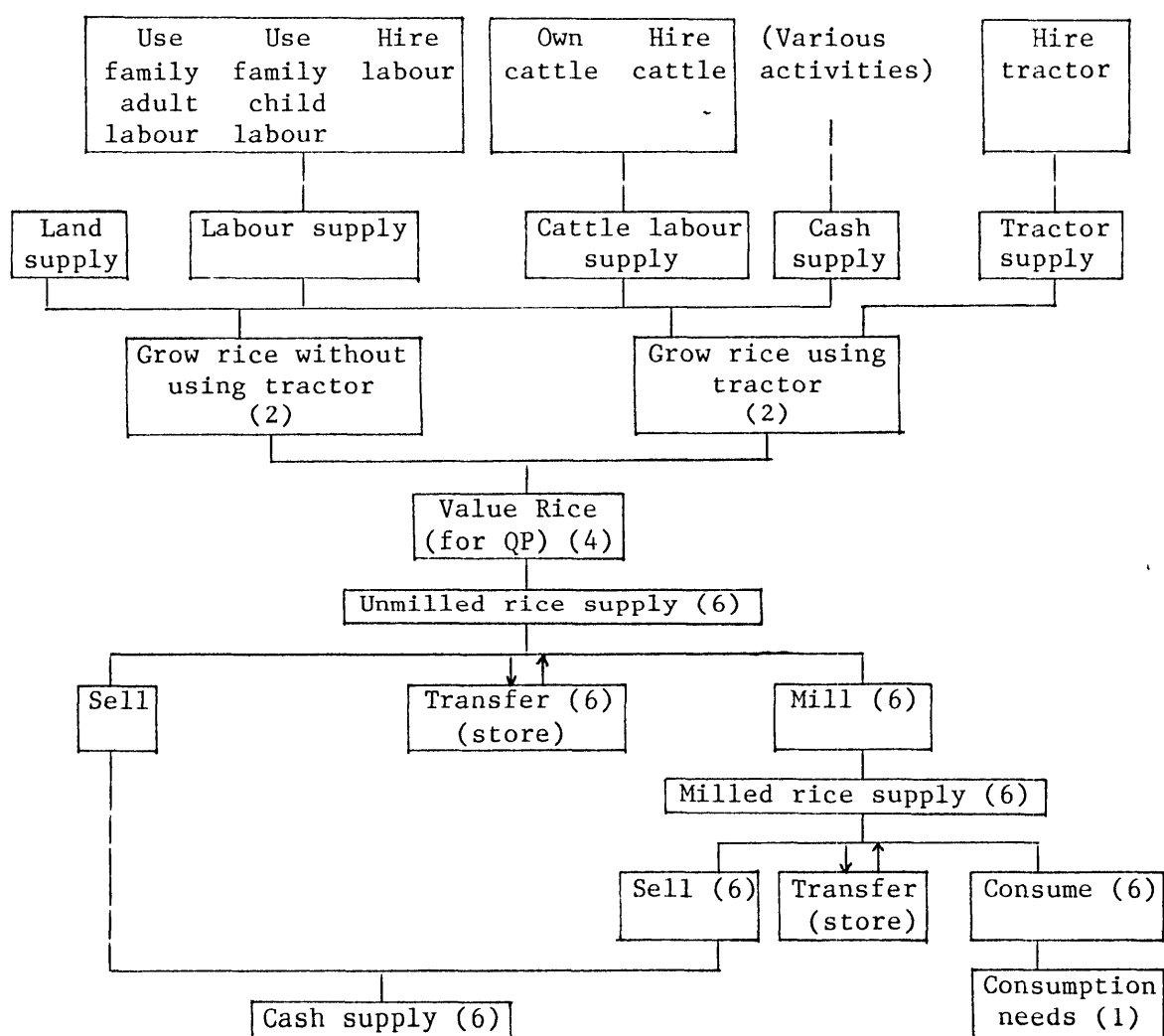


Figure 5.1 Structure of Rice Production Section.

Once the rice had been valued, it could be either sold as unmilled rice, stored for later use, or milled. The milling activities resulted in a supply of milled rice, which in turn could be either sold, stored or consumed. The selling activities contributed to cash supplies, while the consumption activity satisfied the minimum subsistence requirement specified by each farmer.

The structure of the poultry and cattle sections is shown in Figures 5.2 and 5.3 respectively. The 'keeping' of these animals was given a positive (negative for minimisation) objective function value, as were the breeding activities. This accorded with the policy of valuing total farm product. Unrealistic cycles of buying and selling livestock were avoided by allowing farmers either to buy or to sell (but not both), depending on their initial ownership level.

The supply of family labour (adult and child) was constrained in each two-month period. No absolute constraints were set on labour hire in the initial models because none of the sample farmers had experienced difficulties in this regard. Several distinct labour hiring activities were necessary since the rate per man-hour differed according to the task. The importance of labour supply was investigated further in the sensitivity tests discussed in sections 6.2.2 and 6.3.2.

All buying and selling activities affected the cash supply in the appropriate two-month period. Excess supply in one period could be transferred for use in the next period, while credit at two per cent interest per period was available in case of need. Expenditures on essentials such as food, clothing, ceremonies, taxes and school fees were ensured through the 'household cash requirements' activity, constrained to a value of one (times the minimum requirement).

5.2.2 Coefficients and resource levels

Most of the estimates of coefficients and resource levels were based on the questionnaire data summarised in Appendix D. Historical data (Appendix A) were used to supplement subjective estimates where necessary. For instance, mean crop prices were calculated from detrended historical series. This ensured conformity with the variance-covariance

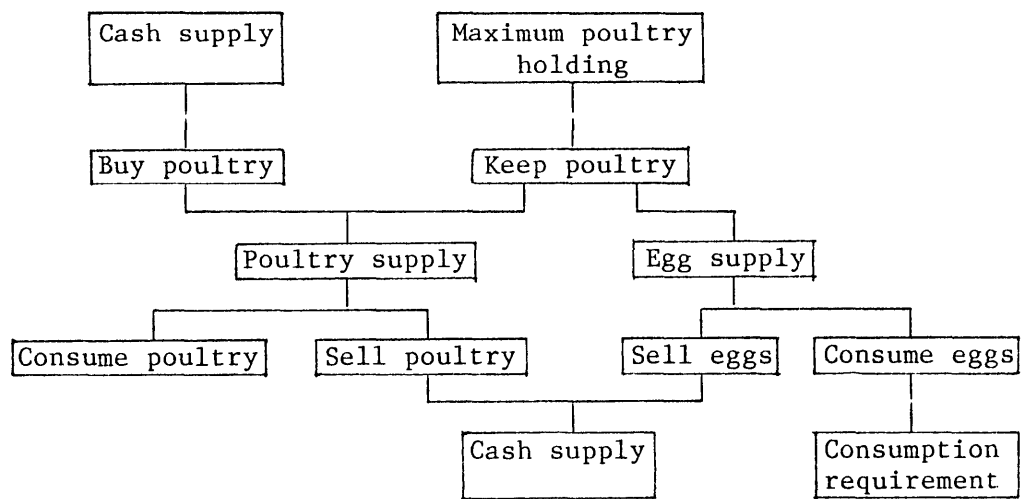


Figure 5.2 Structure of Poultry Section.

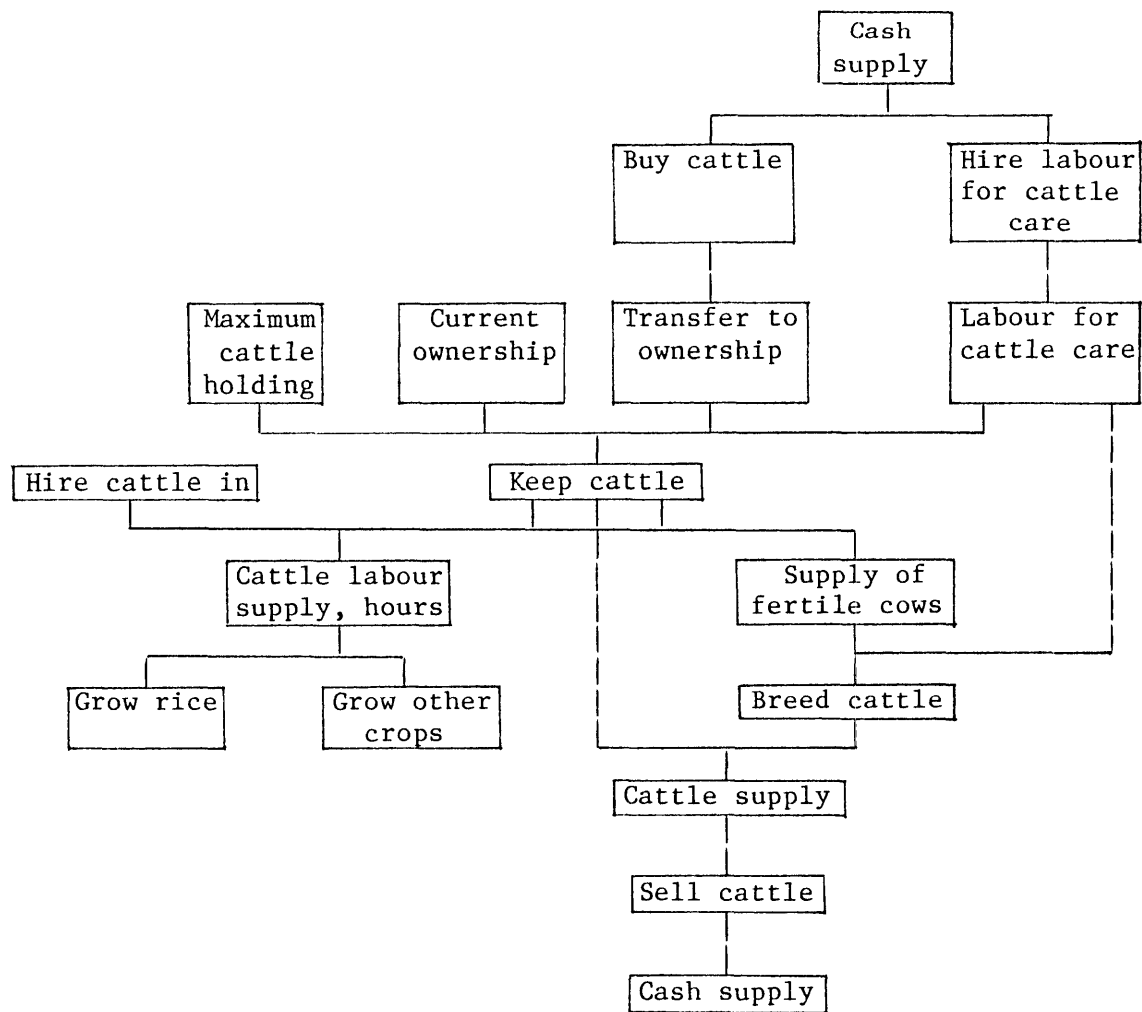


Figure 5.3 Structure of Cattle Section.

matrices used in the quadratic models (see section 5.3). Moreover, it was not feasible to use farmers' questionnaire responses for price estimates. The eight sample farmers reported a total of eleven individuals or organisations to whom they sold their rice. Prices differed both between buyers and between sellers. An attempt to take account of the full range of possibilities would have severely complicated the model while adding little to the elucidation of the issue of tractor and animal use.

Subjective estimates of rice yields with and without tractors were used in the initial models. This temporarily resolved Binswanger's (1978) dichotomy between the 'substitution' and 'net contribution' approaches to tractor research (see section 2.3.2). The three farmers who hired a tractor in 1983 all expected the use of a tractor for land preparation to have a positive effect on yields. This 'net contribution' viewpoint was adopted in the initial programming models for those farmers. The other three farmers followed the 'substitutionist' assumption that yields would not increase. The coefficients used in their initial models consequently reflected this belief. The effect of alternative assumptions is investigated in sections 6.2.2(e) and 6.3.

The coefficients for keeping and breeding cattle and poultry were based on estimates by the Luwu branch of the National Planning Office (BAPPEDA 1983; see Appendix A). These covered net survival rate, proportion of fertile females, live offspring and (for poultry) eggs laid. The estimated production figures corresponded closely with those given by the sample farmers. However, the farmers responded in terms of their actual experiences, whereas the BAPPEDA (1983) data appeared to give a better indication of the risks involved in livestock rearing.

The resource levels (right-hand-side values) calculated for the initial models corresponded closely to farmers' actual resource use during the 1982-83 cropping seasons. Thus, the optimality of farmers' choices between tractor and animal power was investigated on the assumption that resources were currently being used at or near full capacity. This was largely in order to facilitate verification of the models, since it would be reasonable to expect results very close to the

actual farm situations. The importance of the chosen resource constraint values was then examined in sensitivity analyses, as discussed in Chapter 6 (sections 6.2.2 and 6.3.2).

5.3 Variance-Covariance Matrices for Quadratic Risk Programming

Once the linear programming models described above had been constructed and checked, they could be transformed into quadratic risk programming models simply by the addition of variance-covariance matrices. However, it is a requirement of quadratic programming that such matrices be positive semi-definite or positive definite. Estimation of variance-covariance matrices for the rice production activities proved to be a major task in this study. It was later realised that the difficulties encountered were largely the result of the way in which four series of 'gross value' observations were generated from essentially inadequate data. The calculations carried the implicit a priori assumption that returns from tractorised and non-tractorised rice production were perfectly correlated. The consequences and subsequent modification of this assumption are discussed in section 5.3.2.

Since the estimation of mathematically tractable variance-covariance matrices is crucial to the success of quadratic programming, the method and the difficulties are described fully below. An historical matrix was also calculated for rice as an alternative to the 'subjective' matrix. This is discussed in section 5.3.3. The variance estimates for non-rice activities were estimated solely from historical data. The calculations are briefly outlined in section 5.3.4.

5.3.1 Estimation of variance-covariance matrices for rice production

The 'rice valuation' activities described in section 5.2.1 were designed such that each of the four rice production activities in the model was assigned a mean value per hectare. Consequently, the variance-covariance matrix for rice production also had to be expressed in terms of gross value (price x quantity) per hectare. The four activities in the matrix were:

- (a) grow rice using a tractor, dry season;
- (b) grow rice using a tractor, wet season;
- (c) grow rice without a tractor, dry season; and
- (d) grow rice without a tractor, wet season.

The data available for the estimation of the variance-covariance matrices included:

- (a) unmilled rice prices in Bone-Bone district, 1979-83 (monthly);
- (b) yields of unmilled rice in Bone-Bone district, 1974-82 (separate series for dry season and wet season); and
- (c) subjective probability distributions for rice yields (i) with a tractor and (ii) without a tractor.

It will be recalled from section 4.4.4 that the sample farmers were unable to specify conditional probability distributions for yields from the four rice activities. It was therefore necessary to combine subjective yield distributions with historical price time-series to obtain estimates of both the variances of activities and the covariances between activities. The procedure may be briefly summarised as follows:

- (a) estimate the subjective means and variances of yields for tractorised and non-tractorised rice based on the probability distributions elicited from the farmers;
- (b) detrend the historical price and yield series and calculate means and variances for each season;
- (c) combine the means and variances in step (a) with the historical means and variances of prices calculated in step (b). This gives (semi-) 'subjective' estimates of the mean and variance of each of the four rice production activities;

- (d) multiply the price observations in step (b) with the corresponding yield observations from step (b). This gives a historical gross value series for each season;
- (e) normalise the two gross value series in (d) and reconstruct them with the 'subjective' means and variances from step (c). This results in four series corresponding to the four rice production activities;
- (f) compute the variance-covariance matrix of the four series in step (e); and
- (g) test the matrix for positive semi-definiteness prior to incorporating it into the quadratic programming formulation.

Each of these steps is explained in more detail below.

(a) Subjective means and variances of rice yields

The procedure for the elicitation of subjective probability distributions for rice yields has been outlined in section 4.4.4. The judgemental fractile method involves identifying a few points (fractiles) on the cumulative distribution function (CDF). The assumption was adopted in the current study that the probability distributions were approximately normal. The elicited fractile values for each distribution were therefore plotted on normal probability paper (see Anderson et al. 1977, p. 42). Mean yields corresponded to the 0.05 fractile, while variances were given by:

$$(5.1) \quad V(x) = (f_{0.841} - f_{0.5})^2$$

The subjective means and variances of rice yields for the sample farmers are shown respectively in columns 2 and 5 of Table 5.2. It will be noted that identical distributions for dry season and wet season are specified for each farmer. The sample farmers were asked whether they perceived any differences in yield and yield variability between dry and wet

Table 5.2
Means and Variances of Rice Production

Activity*	1 Actual yield/ha 1982/83	2 Estimated mean yield/ha	3 Mean price of unmilled rice	4 Expected value of rice/ha	5 Estimated variance of rice yields	6 Variance of unmilled rice price	7 Variance of rice value/ha
AA1							
T,DS	-	3190	0.12336	393.5184	3417	0.0002439	2534.693
T,WS	-	3190	0.11435	364.7765	3417	0.0000541	595.870
λ,DS	3400	3190	0.12336	393.5184	3417	0.0002439	2534.693
λ,WS	3230	3190	0.11435	364.7765	3417	0.0000541	595.870
AA2							
T,DS	-	4635	0.12336	571.7736	11598	0.0002439	5418.867
T,WS	-	4635	0.11435	530.0120	11598	0.0000541	1315.513
λ,DS	4505	4635	0.12336	571.7736	11598	0.0002439	5418.867
λ,WS	4335	4635	0.11435	530.0120	11598	0.0000541	1315.513
TA1							
T,DS	3400	4335	0.12336	534.7656	66802	0.0002439	5616.100
T,WS	1700	4335	0.11435	495.7070	66802	0.0000541	1894.639
λ,DS	5100	3825	0.12336	471.8520	70021	0.0002439	4650.898
λ,WS	4675	3825	0.11435	437.3887	70021	0.0000541	1711.570
TA2							
T,DS	2720	3315	0.12336	408.9384	30760	0.0002439	3155.760
T,WS	-	3315	0.11435	379.0702	30760	0.0000541	998.903
λ,DS	-	3315	0.12336	408.9384	30760	0.0002439	3155.760
λ,WS	3060	3315	0.11435	379.0702	30760	0.0000541	998.903
TT1							
T,DS	3825	4400	0.12336	542.7840	371162	0.0002439	10460.460
T,WS	4675	4400	0.11435	503.1400	371162	0.0000541	5921.649
λ,DS	-	3500	0.12336	431.7600	23669	0.0002439	3353.613
λ,WS	-	3500	0.11435	400.2250	23669	0.0000541	974.064
TT2							
T,DS	4650	4950	0.12336	610.6320	21813	0.0002439	6313.178
T,WS	5000	4950	0.11435	566.0325	21813	0.0000541	1613.119
λ,DS	-	3900	0.12336	481.1040	145572	0.0002439	5960.340
λ,WS	-	3900	0.11435	445.9650	145572	0.0000541	2734.931

* T denotes tractorised production; λ denotes non-tractorised production;
DS is dry season and WS is wet season.

seasons, but none of them could identify a clear trend. Consequently, a single elicitation was carried out and the results applied to both seasons.

(b) Means and variances of detrended historical prices and yields

The historical series for rice prices and yields were detrended using the Shazam routine shown in Appendix F1. Each observation was expressed in terms of current (final observation) yields (1982) or prices (1983). Simple linear effects of inflation and agricultural improvements were thereby removed. The price series was then disaggregated into two seasonal series. Since the dry season harvest was in November, price observations from November to April were categorised as dry season prices while those following the May harvest (May-October) were categorised as wet season prices. Shazam was then used to calculate the means and variances of the detrended series. These are shown in Table 5.2 in columns 3 and 6 respectively.

(c) Calculation of means and variances for rice gross values

The subjective data on tractorised and non-tractorised rice yields were combined with historical price data for dry and wet seasons to give estimates in terms of gross values. Mean gross values for the four rice production activities were obtained by simply multiplying mean prices by mean yields. However, estimation of the variances was more demanding. Goldberger (1970, p. 154) gives a formula for the variance of the product of two distributions such as prices (x_1) and yields (x_2):

Suppose that the random variables x_1 and x_2 have means u_1 and u_2 , variances $\text{Var}(x_1)$ and $\text{Var}(x_2)$, and covariance $\text{Cov}(x_1, x_2)$. Then the variance of their product $y(=x_1x_2)$ is ...

$$[(5.2)] \quad \text{Var}(y) = A + B + C + D + F + G$$

where

$$A = u_2^2 \text{Var}(x_1),$$

$$B = u_1^2 \text{Var}(x_2),$$

$$C = 2u_1u_2 \text{Cov}(x_1, x_2),$$

$$D = E[(x_1 - u_1)(x_2 - u_2) - \text{Cov}(x_1, x_2)]^2,$$

$$F = 2u_1E[(x_1 - u_1)(x_2 - u_2)^2],$$

$$G = 2u_2E[(x_1 - u_1)^2(x_2 - u_2)],$$

and E is used to denote the expectation operator.

While criticising other authors (e.g. Burt and Finley 1968) for ignoring the terms D, F and G, Goldberger notes that if x_1 and x_2 are assumed to be independent, the formula reduces to (Goldberger 1970, p. 154):

$$[(5.3)] \quad \text{Var}(y) = u_2^2 \text{Var}(x_1) + u_1^2 \text{Var}(x_2) + \text{Var}(x_1)\text{Var}(x_2).$$

For the current study, no estimates were available of the covariance between subjective yield and historical price distributions. Moreover, the subjective yield distributions were in the form of CDFs and did not consist of actual observations. This meant that it was not possible to calculate terms D, F and G in equation (5.2). It therefore appeared reasonable to accept equation (5.3) for present purposes. A simple BASIC program was used to facilitate computation (see Appendix F2). The resulting variance estimates for all sample farmers are summarised in column 7 of Table 5.2.

(d) Calculation of historical gross value series

Steps (a) to (c) above resulted in estimates of the mean and variance of gross value for the four rice production activities. The next stage was to use historical data for the estimation of the covariances between the activities. This required the computation of an historical gross value series. Gross values were calculated by multiplying each yield observation from 1979-82 by each of the six monthly price observations which followed. The assumption here, which corresponded to the structure of the programming model, was that a farmer might sell rice at any time between harvests. This procedure resulted in twenty-four observations of the gross value of rice production in each season.

(e) Normalisation and reconstruction of gross value series

The next step was to combine the two historical gross value series with subjective data which differentiated between tractorised and non-tractorised production. Subjective variances and historical covariances were thus used within a single variance-covariance matrix. This could only be done by first normalising the historical series and then reconstructing them to conform in turn with each farmer's subjective means and variances (Lin 1973, Sharif forthcoming). The normalisation process for each observation was as follows:

$$(5.4) \quad \text{GVN} = (\text{GV}_h - E(\text{GV}_h)) / \text{SD}(\text{GV}_h),$$

where GVN = normalised gross value observation;
 GV_h = an historical gross value observation;
 $E(\text{GV}_h)$ = the mean of the historical gross value series; and
 $\text{SD}(\text{GV}_h)$ = the standard deviation of the historical gross value series.

The reconstruction process was essentially equation (5.4) in reverse:

$$(5.5) \quad \text{GVR} = (\text{GVN} * \text{SD}(\text{GV}_s)) + E(\text{GV}_s),$$

where GVR = reconstructed gross value observation;
 GV_h = an historical gross value observation;
 $\text{SD}(\text{GV}_s)$ = the standard deviation of the subjective gross value series; and
 $E(\text{GV}_s)$ = the mean of the subjective gross value series.

Equation (5.5) was repeated twice, using first tractorised and then non-tractorised subjective variances (see Appendix F3 for Shazam routine). These linear transformations had no effect on the correlations between variables.

(f) Computation of variance-covariance matrix

The variance-covariance matrices to be used for quadratic programming were computed from the four reconstructed gross value series obtained for each farmer in step (e). The BASIC routine is listed in Appendix F4 and the resulting matrices are shown in Appendix G.

(g) Test for positive semi-definiteness

Variance-covariance matrices calculated from actual observations have the essential mathematical property of positive (semi-)definiteness. This means that all eigenvalues (characteristic roots) are non-negative. The procedure outlined above for the calculation of variance-covariance matrices should have guaranteed positive semi-definiteness. However, in view of the difficulties outlined in section 5.3.2, the eigenvalue test was considered to be an essential final stage of the calculation of variance-covariance matrices. The Fortran program listed in Appendix F5 was used in conjunction with a NAGF02 subroutine (NAG Fortran Library 1975) for this purpose.

5.3.2 Difficulties encountered

The difficulties initially encountered in the estimation of positive semi-definite matrices were in relation to an earlier version of the programming models. The intention then had been to compute variances and covariances for each of twenty-four rice selling activities (tractorised and non-tractorised unmilled and milled rice in six periods). A simple conversion factor was used to obtain a 'milled rice yield' series from the unmilled rice figures, while a separate series was available for milled rice prices. Calculation of the 24 x 24 matrix followed essentially the same steps as those outlined in section 5.3.1, with the exception that each price series was disaggregated into two-month, rather than seasonal, periods. The resulting matrix for one of the sample farmers was incorporated into his programming model, but it was found that an optimal solution could not be obtained.² The test for positive

² The rather ambiguous error message 'too many entries in inverse' was printed instead.

semi-definiteness was then carried out. This revealed that nine of the twenty-four eigenvalues were negative.

The above result contradicted mathematical theory. It was therefore concluded that rounding errors were the immediate cause of the problem. The effect of rounding errors is potentially more crucial in the case of a positive semi-definite matrix (where some eigenvalues are zero) than with a positive definite matrix (where all eigenvalues are positive). A matrix is likely to be positive semi-definite if its variables are linearly related. Linear relations existed in the matrix calculated because each data series had been used more than once to generate a large number of variables. Thus, even when the matrix was recalculated to a higher degree of precision, negative eigenvalues remained. It seemed probable that rounding errors would continue to prevent successful quadratic programming. The programming models were therefore modified so that only the four variables discussed in section 5.3.1 had to be included in the variance-covariance matrix.

Unfortunately the problem remained, since the tractorised and non-tractorised activities were still linearly related. In the absence of separate historical data series for tractorised and non-tractorised rice yields, a single undifferentiated yield series for each season had been used to generate observations for each pair of rice production variables (step (e)). Thus, the two variables generated for each season were perfectly correlated. As before, the requirement of positive semi-definiteness could only be achieved if the elements in the matrix were expressed to an extremely high degree of precision.

The correlation coefficients of 1.0 should be seen as a result of the way in which data inadequacies were handled, rather than as evidence of a conscious decision to assume perfect correlations. Consequently, when it became clear that the variance-covariance matrix for rice production would have to be modified to achieve mathematical tractability, the logical solution seemed to be a reduction of the correlation coefficients. In fact there were good a priori reasons for assuming that the gross values of rice produced with the two techniques would be highly - but not perfectly - correlated. A high correlation

could be justified on the following grounds:

- (a) the price of rice was considered to be independent of the production technique (assuming individual farmers were price takers), and so price variability affected each gross value series to the same extent;
- (b) exogenous factors such as rainfall were probably responsible for much of the variation in rice yields. The influence of such factors might be expected to bear little relation to the technique of land preparation. However, potential effects of tractor use on depth of tillage and timeliness (see Chapter 2) might account for less-than-perfect correlation; and
- (c) a correlation coefficient of 0.838 was calculated between the two seasonal gross value series compiled from historical data. Assuming that climatic variability is relatively important for rice production, it seems reasonable to expect a higher correlation between the value of production by two techniques in the one season, than by one technique in two different seasons.

On these grounds it was decided that the correlation coefficients should be set somewhere between 0.838 and 0.999. An initial experiment with correlations of 0.99 failed to resolve the problem of mathematical tractability discussed above. The value of 0.9 seemed to be a realistic compromise from the viewpoints both of mathematics and of a priori reasoning. A reduction from 1.0 to 0.9 resulted in the positive definite variance-covariance matrices shown in Appendix G.

Subsequent sensitivity analyses focussed on variances rather than correlations (see section 5.3.3). While it might also have been useful to investigate the sensitivity of the results to the correlation coefficients assumed, time constraints precluded undertaking such an additional computational task. It is believed that the assumed values were reasonable estimates in the context of the data limitations outlined above.

5.3.3 Historical variance-covariance matrix for rice production

The variance-covariance matrices discussed above are henceforth denoted 'subjective' matrices in spite of the fact that historical data were used to supplement the subjective probability estimates. These matrices are considered to be the closest possible approximations of the beliefs of the sample farmers, given the problems of data unavailability. However, alternative estimates were desirable for the purposes of sensitivity analysis. Another matrix was therefore calculated entirely from historical data. This involved carrying out steps (b) and (e) of section 5.3.1 and assuming a correlation coefficient of 0.9 between tractorised and non-tractorised production. The coefficient of 0.9 was deliberately chosen to conform with the coefficient used in the 'subjective' matrices (see section 5.3.2). The resulting 'historical' matrix is shown in Appendix G, while the effect of substituting the historical matrix and its corresponding mean (expected) values for the subjective matrices and mean values is discussed in Chapter 6.

5.3.4 Variance-covariance matrices for non-rice activities

As mentioned in section 5.2, non-rice crops (maize and peanuts) were included in just two of the farm models. Variances were estimated for these crops from the historical price and yield data presented in Appendix A. A scaling factor was applied to each series so that the mean price and yield equalled those actually obtained by the farmer. The variance of crop value was then calculated using equation (5.3). Two crops of maize were grown, but no data were available which differentiated between them. A coefficient of 0.9 was used for the correlation between wet and dry season crops, in line with earlier practice. In the case of peanuts, only one productive activity (dry season) was involved.

Crude estimates were also made of the risks of keeping and breeding cattle and poultry. The only data which could be used for this purpose were the BAPPEDA (1983) production figures cited in section 5.2.2 along with price data for 1980-83. The BAPPEDA estimate of net survival rate was multiplied by the mean price to give a mean value of the keeping of

livestock. It was then assumed that a survival rate of 100 per cent corresponded to the 0.9999 fractile of a normal cumulative distribution function. Variances were estimated from these functions. A similar procedure was followed for the 'calves born', 'eggs laid' and 'chickens hatched' activities. No claims can be made as to the accuracy of these estimates, but the results summarised in Chapter 6 suggest that the estimates were of minor significance in determining the optimal solution.

5.4 Concluding Remarks

The programming models developed for the present study have been discussed in this chapter. The model-building process began with the construction of linear models. These were carefully checked so as to ensure that they functioned as intended. The model design was such that they could be converted into quadratic models simply by the inclusion of variance-covariance matrices. Variances and covariances for rice production were estimated from a combination of historical and subjective data. The procedure has been summarised in section 5.3.1, while some difficulties were mentioned in section 5.3.2. These difficulties led to a substantial revision of an earlier version of the programming models. The computational complexity of the models was significantly reduced but their essential features were maintained. The results of running these models are presented in the following chapter.