AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

ECONOMICS OF TECHNICAL CHANGE IN WHEAT PRODUCTION IN PUNJAB (INDIA)

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA

BY
SURJIT SINGH SIDHU

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DECEMBER 1972

ACKNOWLEDGMENTS

I owe a special debt of gratitude to Professor Lee R. Martin, chairman of my graduate committee at the University of Minnesota. Without his encouragement and help during my graduate work, this thesis could not have been possible. He made relevance and accuracy a prime consideration. My profound thanks are due to Professor Vernon W. Ruttan who managed financial support for the project both in India and Minnesota and provided immeasurable help in the development of the project and seeing it through to the end. I also wish to thank professors Willis Peterson, Reynold P. Dahl and Leonid Hurwicz for giving me helpful suggestions and guidance at various stages of my dissertation work.

I gratefully acknowledge the financial support of the Rockefeller Foundation and the Economic Development Center, University of Minnesota during the period of this research. I also thank the Department of Economics and Statistics, Ministry of Food and Agriculture, Government of India and Economic Adviser, Government of Punjab for allowing me to use their data for this research. My special thanks are also due to the office of Ohio State University Contract Team at Punjab Agricultural University, Ludhiana, for assisting me in data collection work in various ways.

I also must make acknowledgments to the following persons:

Dr. Neal R. Carpenter for initiating me into the field of economics and encouraging me to pursue graduate studies;

Dr. W. David Hopper for initiating the research project and for arranging financial support;

Dr. Martin E. Abel for constructive suggestions and guidance at various stages of my dissertation work;

Dr. L. S. Venkataramanan for providing advice and space at Indian Agricultural Research Institute, during my stay in India;

Dr. Dalip S. Sidhu for help and suggestions in data collection work;

Henry Hwang and Sachiko Yamashita for their help in computer work without which this work could never have been possible;

Mary Strait and Barbara Miller for their computational help;

Carol Lieb for her excellent typing;

numerous friends and farmers in Punjab, the list of whose names is too long to be reproduced here, for assisting and cooperating in data collection work;

and lastly my father, Isher S. Sidhu, who waited too long.

TABLE OF CONTENTS

		Page
ACKNOWLEDGMENTS		ii
LIST OF TABLES		vii
CHAPTER		
I.	INTRODUCTION	1
	Objectives	3
	The Assumptions for the Analysis and the Economic Characteristics of Wheat Industry	4
II.	THEORETICAL AND OPERATIONAL FRAMEWORK	8
	Production Function Model	8
	Cost Function Model	15
	Profit Function Model	19
III.	THE DATA, THE REGION AND THE VARIABLES	36
	Samples and Sources	36
	The Region	41
	The Variables	43
IV.	EMPIRICAL RESULTS AND THEIR INTERPRETATION: OLD *VERSUS* NEW WHEATS	47
	Production Function Model	47
	Input Demand Functions	52
	Cost Function Model	55
	Profit Function Model	58
	Summary	64

TABLE OF CONTENTS
(continued)

CHAPTER | Page

V. EMPIRICAL RESULTS AND THEIR INTERPRETATION: PRODUCTION AND COST RELATIONSHIPS FOR THE NEW WHEAT AND ROLE OF EDUCATION IN PRODUCTION, 1967/68 - 1970/71. 66

Production Function Model 66

Education and Animal Power as Factors of Production 73

Cost Function Model 84

Profit Function Model 90

Summary 102

VI. EMPIRICAL RESULTS AND THEIR INTERPRETATION: RELATIVE ECONOMIC EFFICIENCY--SMALL VERSUS LARGE FARMS 105

Production Function for Small and Large Wheat Farms .. 107

Relative Efficiency: Profit Function Formulation 109

Summary 127

VII. EMPIRICAL RESULTS AND THEIR INTERPRETATION: TRACTOR VERSUS NON-TRACTOR FARMS 129

Production Function Model 132

Profit Function Model 143

Cost Function Model 149

Summary and Policy Implications 153

VIII. SUMMARY AND CONCLUSIONS 157

Empirical Findings and Conclusions 159

Policy Implications 169

TABLE OF CONTENTS
(continued)

APPENDICES

		Page
I.	The Context of Punjab Wheat Production	175
II.	Test for the Maintained Cobb-Douglas Hypothesis	191
III.	Zero-Order Correlations	193
IV.	Additional Regression Results	199
V.	Size Distribution of Sample Farms	202
BIBLIOGRAPHY		204

LIST OF TABLES

TABLE		Page
3.1	DESCRIPTION OF THE REGIONALLY STRATIFIED SAMPLE	40
3.2	BRIEF SUMMARY OF THE SAMPLES AND DATA	42
4.1	ESTIMATES OF PRODUCTION FUNCTION FOR WHEAT, 1967/68, PUNJAB, INDIA.	48
4.2	ESTIMATES OF COST FUNCTION FOR WHEAT BASED ON EQUATION 2.10, 1967/68, PUNJAB, INDIA	56
4.3	INPUT ELASTICITIES AND RETURNS TO SCALE DERIVED FROM ESTIMATES OF THE COST FUNCTION PRESENTED IN TABLE 4.2 .	57
4.4	RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR WHEAT, 1967/68, PUNJAB, INDIA	60
4.5	ESTIMATES OF OUTPUT ELASTICITIES FOR WHEAT PRODUCTION FUNCTION, 1967/68, PUNJAB, INDIA	61
4.6	AVERAGE AND MARGINAL VALUE PRODUCTS FOR DIFFERENT INPUTS IN THE PRODUCTION OF OLD AND NEW WHEAT, 1967/68, PUNJAB, INDIA	63
5.1	ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	68
5.2	ESTIMATE OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	69
5.3	PRODUCTION FUNCTION FOR WHEAT, 1967/68, PUNJAB, INDIA, INCLUDING EDUCTION AS A SEPARATE VARIABLE	77
5.4	PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68, 1968/69, AND 1970/71, PUNJAB, INDIA, INCLUDING EDUCATION AS A SEPARATE VARIABLE	78
5.5	ESTIMATES OF THE COST FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	85
5.6	ESTIMATES OF COST FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	86

LIST OF TABLES
(continued)

TABLE		Page
5.7	PARAMETERS OF THE COBB-DOUGLAS PRODUCTION FUNCTION DERIVED FROM COST FUNCTION ESTIMATES, 1967/68 - 1970/71, PUNJAB, INDIA	88
5.8	RESULTS OF JOINT ESTIMATION FOR NEW WHEAT OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION, 1967/68 - 1970/71, PUNJAB, INDIA	92
5.9	PRODUCTION FUNCTION ESTIMATES OF NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	93
5.10	EXPENDITURE SHARES OF VARIOUS INPUTS AT SAMPLE GEOMETRIC MEANS IN TOTAL REVENUE AND TOTAL COST IN THE PRODUCTION OF NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	95
5.11	AVERAGE AND MARGINAL VALUE PRODUCTS FOR DIFFERENT INPUTS IN THE PRODUCTION OF NEW WHEAT, 1967/68 - 1970/71	96
6.1	ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	108
6.2	RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1967/68, PUNJAB, INDIA	111
6.3	RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1968/69, PUNJAB, INDIA	113
6.4	RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1969/70, PUNJAB, INDIA	114
6.5	RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1970/71, PUNJAB, INDIA	115
6.6	RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	116
6.7	TESTING OF STATISTICAL HYPOTHESES, MODEL II AND MODEL III	118

LIST OF TABLES
(continued)

TABLE		Page
6.8	ESTIMATES OF THE INPUT ELASTICITIES OF THE COBB-DOUGLAS PRODUCTION FUNCTION DERIVED FROM THE PROFIT FUNCTION, NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	124
7.1	PER ACRE INPUT USE AND SOME OTHER STATISTICS AT SAMPLE MEANS, NEW WHEAT, 1969/70, PUNJAB, INDIA	131
7.2	INPUT-OUTPUT COEFFICIENTS PER QUINTAL OF WHEAT AT SAMPLE MEANS, NEW WHEAT, 1969/70, PUNJAB, INDIA	132
7.3	ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1969/70, TRACTOR AND NON-TRACTOR FARMS, PUNJAB, INDIA	135
7.4	ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, TRACTOR AND NON-TRACTOR FARMS, WITH SLOPE DUMMIES, 1969/70, PUNJAB, INDIA	137
7.5	EXPENDITURE SHARES AT SAMPLE GEOMETRIC MEANS, NEW WHEAT, 1969/70, PUNJAB, INDIA	140
7.6	ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1969/70, TRACTOR AND NON-TRACTOR FARMS, PUNJAB, INDIA	141
7.7	RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1969/70, PUNJAB, INDIA	144
7.8	ESTIMATES OF COST FUNCTION FOR NEW WHEAT, TRACTOR AND NON-TRACTOR FARMS, 1969/70, PUNJAB, INDIA	150

LIST OF APPENDIX TABLES

I.1	SOIL ZONES OF THE PUNJAB, INDIA	179
I.2	PERCENT OF WHEAT AREA PLANTED TO NEW WHEAT IN WHEAT GROWING STATES OF INDIA, 1966/67 - 1969/70	181
I.3	SOME SELECTED GROWTH INDICATORS, 1950/51 - 1969/70, PUNJAB, INDIA	182

LIST OF TABLES
(continued)

TABLE		Page
I.4	RELATIVE PERFORMANCE OF NEW WHEATS VS C.306, PUNJAB AGRICULTURAL UNIVERSITY, LUDHIANA	188
III.1	ZERO-ORDER CORRELATION MATRICES, LOGARITHMS OF VARIABLES	194
IV.1	ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	200
IV.2	ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA	201
V.1	SIZE DISTRIBUTION OF SAMPLE FARMS	203

CHAPTER I

INTRODUCTION

The spread of high-yielding cereal varieties particularly of wheat and rice since 1965 has ushered an era of great agricultural transformations in many parts of Asia. This has allayed the fear of the Malthusian spectre[1/] and generated new hopes for these countries. The realizable potential improves the prospects for sustained growth of these economies. The challenge facing policymakers and planners of these and other less developed countries is how to convert the potential into a sustained basis for the furtherance and continuation of the process of transformation.

Whereas the technological breakthrough in cereal production in Asia popularly known as 'green revolution' has obviously generated increased agricultural output and farm incomes, the distribution of these gains by no means seems to be even. Larger land owners--in addition to the increased farm incomes--are realizing large capital gains on their landed property. They are thus benefitting far more than are small farmers and laborers. This may constitute another challenge to the policymakers of these countries, that is, how to design fiscal programs

---

[1/] For example Myrdal (1968) considers India and some other densely populated areas of Asia as evidence of Malthusian thesis. Also see Paddock and Paddock (1967) for a dramatized view of famine possibilities and Cochrane (1969) for an optimistic view.

which will redistribute the gains from the new agricultural technology more evenly among the various social classes.

The answers to these challenges are by no means easy to intuit. At the very least it requires an understanding of the nature and impact of the transformation that has already occurred in several LDC's and is underway in many others. What we need is not a simple impressionistic assessment of this change but quantitative measures which could be usefully employed in applications of economic theory for developmental policy.

The replacement of older cereal varieties by the high-yielding varieties can conveniently be described as "technical change," that is as a change in the production function. It follows that the theory of production is the relevant framework to analyze this change. In the case of wheat[1/] northwestern parts of India and Pakistan have achieved significant increases in yields and output. For the purpose of this study an attempt is made to determine empirically the parameters of this change in the case of Indian Punjab,[2/] in the center of the Indo-Pakistan wheat growing region.

[1/] The Punjab farms are multi-enterprise farms. This study deals only with wheat, not all enterprises on these farms.

[2/] See Chapter III, for brief discussion of the Punjab Region of India and Appendix I for some of the problems which have a bearing on motivation for this study.

Objectives

1. What is the nature of production technology of the "New Wheat" compared to the "Old Wheat?" That is, is the technical change in the form of high-yielding varieties of the neutral or non-neutral type? What are the differences in the long-run cost functions of new and old wheats? What kind of differences have these changes created in the factor demand functions, particularly the labor demand function? And what is the magnitude of gains to the country from adaptation of high-yielding wheat varieties? The first objective of the present study is to provide answers to this set of questions. In obvious ways this information will have great importance and use in furtherance of the process of agricultural transformation.

2. Another set of questions describes the second objective. How does the economic efficiency of small wheat farms compare with large ones, and how does the economic efficiency of tractor-operated wheat farms compare with non-tractor-operated ones? Are there differences in their technical and/or price efficiency? Are they price-efficient, that is, are they able to maximize profits? Such knowledge has implications for land reforms, policies for mechanization, informational services and improved efficiency of resource use.

3. Did the introduction of high-yielding varieties of wheat--technical change--create some sort of disequilibrium between the production and cost relationships on the one hand and profit-maximizing attempts of the wheat producers? If so what type of behavioral adjustments occurred over the four year period--1967/68 to 1970/71? How did the long-run cost function change over this period? Answers to these

questions will provide information to evaluate the various kinds of influences on the factor markets.

4. Another objective set forth for this study is to develop estimates of the elasticities of output supply and labor demand with respect to output price, wage rate and quantities of land and capital. These estimates are of crucial importance in planning for output and employment objectives.

5. Lastly we want to explore the role of education in production. The problem assumes greater significance and interest in the context of recent technical shifts which may have raised the demand for the educational input.

The pursuit of these objectives will also provide information on the existence of economies of scale in wheat production and enable us to explore its implications with respect to farm size adjustments.

The Assumptions for the Analyses and the Economic Characteristics of Wheat Industry

For the purposes of subsequent analyses in this study we make the following assumptions.

1. Farmers are price takers in both the product and factor markets.

For the product market price of wheat is supported by the government, and is announced before the marketing season starts. During the past four seasons the procurement price of 'New Wheat' has been stable at about Rupees 76 per quintal and 'Old Wheat' at about Rupees 81 per quintal. Thus, even though procurement prices are announced only a little while before the harvest season starts, the farmer's expectation is a continuation of the last year's price as more or less an assured price for his decision making purposes. And in fact, all his marketings are carried out at this assured price on which his revenues depend.

For factor markets the following situation holds: fertilizer prices are set by the government and are maintained at a uniform level all across the region during a production period. Supplies at fixed prices are made available at the village level by the State Marketing Federation through the village cooperative societies.[1/]

The level of wages of both annual and daily hired labor are pretty much determined in competition in the village market. This market sometimes extends over several small contiguous villages.

The annual rental of rented lands also is fairly competitively determined in village markets. The hiring of land services is quite common.[2/] The form of payment, i.e., cash or share in output, does not seem to distort the underlying competitive demand and supply conditions.

The assumption that markets for labor and land services are competitive does not mean that there are no price variations among farms, only that these variations are due to geographical location. Put differently the levels of the supply curves for these factors can differ from firm to firm but not the elasticities of these curves.

[1/] It is a private cooperative almost completely controlled and dominated by the state government.

[2/] See Sethuraman (March 1970, p. 16).

The capital market does exhibit certain kinds of imperfections. First of all, long-period loans are not easily available to smaller and poorer farms. Also transactions costs are independent of the loan amounts. In some cases certain types of capital costs are indirectly subsidized for larger producers. Supply of electricity for irrigation purposes is a case in point.[1/] The influences of these distortions will be discussed in appropriate cases. Since we do not have data about these imperfections the assumption of a competitive capital market will be maintained.

2. The privately managed farm is the economically relevant unit of analysis.

Punjab farming is dominantly of the peasant-proprietor type. Singh and Billings (January 1971), report that 52 percent of the cultivators farm entirely owned land, 34 percent rent some land to augment their operational units, and 14 percent are exclusively tenants. Average operational farm size is about 12 acres, with about 60 percent units larger than 7.5 acres and 12 percent smaller than 2.5 acres. Nearly all wheat is produced by privately managed farms.

3. Since technical change (both neutral and non-neutral) can conveniently be defined in terms of certain characteristics of a production

---

[1/] Electricity charges are at a fixed rate of approximately Rs 8.50 per month per horse power of the motor used and are thus independent of the electricity used. See G.S. Brar and H.S. Sandhu (1969) for details of rate structure for different sizes of electric motors. Also see C.H. Hanumantha Rao (Feb. 1972) for arguing that farm machinery has been made artificially cheap through liberal import policy and through the extension of institutional credit for the purchase of tractors on unduely liberal terms.

function the neoclassical production theory is the basic tool for analysis in this study. In view of the simplicity and the desirable set of neoclassical properties of the Cobb-Douglas production function--properties which facilitate the measurement and interpretation of technical change--this function is considered quite suitable for purposes of this study.

The framework underlying the empirical analysis is developed in Chapter II. In Chapter III, the data and the variables used are discussed. In Chapter IV we present the empirical findings comparing changes in production and cost functions for old and new wheats and study the resultant shifts in factor demand functions. The nature and magnitudes of change in the new wheat production and cost functions over the four year period 1967/68 to 1970/71 are explored in Chapter V. In this chapter we also compare the production function estimates obtained from three different estimation techniques and present estimates for the labor demand and output supply elasticities with respect to wage rate, price of output and the quantities of land and capital. Here we also study the role of education as a factor of production and introduce draft animals as a separate input. In Chapter VI the relative economic efficiency of small and large farms is compared. Chapter VII compares the relative economic efficiency of tractor operated versus non-tractor operated wheat farms. Finally in Chapter VIII the empirical findings and the conclusions that emerge are summarized and the implications of the analysis for developmental policy are explored.

CHAPTER II

THEORETICAL AND OPERATIONAL FRAMEWORK

For empirical implementation of the objectives listed in Chapter I, three different but interrelated models are proposed. An examination of 'Technical Change' can most conveniently be carried out by use of the theory of production. We first develop a simple production model based on the standard neoclassical production function. Second, we make use of a cost function model essentially developed by Nerlove (1965). And third, we adapt profit function models developed by Lau (Memorandums 86A and 86B, 1969) and subsequently used by Lau and Yotopoulos (March 1971, February 1972 and Memorandums 104 and 108). None of these models singly accomplishes all our objectives. Each has shortcomings for our purposes but their combined use enables us to accomplish what we want. Before proceeding further it seems worth to mention again that we are dealing only with wheat not all enterprises on the wheat farms.

Production Function Model

Let wheat production function be represented by:

(2.1) $$Y = F(N,L,K)$$

where Y is physical rate of output and N, L and K are input rates of labor, land and capital services respectively, during a given period of production.

If we assume that the form of the production function is of the Cobb-Doublas type, (2.1) may be written:

$$Y = A\, N^{\alpha_1} L^{\alpha_2} K^{\alpha_3} \exp(\delta j + u) \qquad (2.2)$$

where δj denotes the coefficient of the j^{th} dummy variable designed to capture appropriate 'effects'. u is the random disturbance term independently distributed with zero mean and finite variance. We have here decomposed the usual error term into two components, a measure of the neutral variations in efficiency[1/] among farms δ, and the residual term u. This formulation enables us to identify neutral productivity differences among old and new varieties of wheat, among small and large farms, among tractor and nontractor farms and over time, maintaining the hypothesis that there are no non-neutral differences in the respective technologies. Because our objective is to sort out the nature of differences among these technologies, the hypothesis that non-neutral technical differences are absent (technical change is of the neutral type) is empirically tested in each case.

In case we wish to assess the impact of additional variables like fertilizers, animal power and education, the model can be appropriately extended to more than three variables. There are two points

---

[1/] Neutral variation in efficiency in this case means that only the constant A varies from farm to farm and not the output elasticities with respect to various inputs. An increase in the efficiency parameter A represents a neutral technological gain. See also Zellner et. al. (Oct. 1966, p. 786) for a discussion of the neutral disembodied productivity differential.

to be considered in relation to the choice of the Cobb-Douglas form. Firstly, does such a function represent the conditions of wheat production correctly? Put differently the point is associated with substitution possibilities between different inputs. The form of Cobb-Douglas production function implies a unitary elasticity of substitution between any pair of inputs and the question is whether it should be tested rather than assumed beforehand. Hayami (May 1970), Hayami-Ruttan (1971, pp. 102-107) in their test using intercountry cross-section data found their results consistent with unitary elasticity of substitution. Lau and Yotopoulos (June 1970) report that they fitted Indian data to a CES production function directly with nonlinear methods, and found the elasticity of substitution not to be significantly different from one.[1/] Following Kmenta (June 1967) we estimate a CES production function using our data for the four year period (1967/68 to 1970/71) for New Wheat. The results (Appendix II) indicate that we cannot reject the hypothesis that Cobb-Douglas form represents the data adequately.

There is, however, another property of the Cobb-Douglas function, which is both an advantage and a defect. The degree of returns to scale[2/] is invariant with the level of output (Nerlove 1965). We can

---

[1/] They have reported this result from another paper by Yotopoulos, Lau and Somel (1970) not reviewed here. With respect to proper specification of a relation, see also Theil (1971, pp. 540-556).

[2/] The degree of returns to scale for the Cobb-Douglas production function is equal to the sum of output elasticities with respect to all inputs.

measure to see if the degree of homogeneity of the function is greater than, equal to, or less than one. This is valuable in itself. But it is not possible to ascertain if there are additional economies of scale within the output range studied or to ascertain the sources of the economies of scale. Griliches (August 1963) discussed this point and concluded: "To study the subject of economies of scale adequately will require the use of a production function that is not homogeneous over at least some range of the inputs." If the sample size is large enough, one way out of this difficulty is to split the sample into a few size groups and fit segments of functions linear in logarithms and see how the degree of homogeneity behaves for different output ranges. Ulvelling and Fletcher (May 1970) introduced an interesting modification by postulating input elasticities of the Cobb-Douglas production function as functions of some influencing variable(s) (for example, capital intensity), thus converting the conventional Cobb-Douglas function into a variable returns to scale production function.

On the use of straightforward single equation least-squares regression techniques for estimation of production models, there are numerous admonitions and warnings in the literature. The earliest one came from Haavelmo (January 1943) when he considered the importance and implications of introducing error variables in equations of a simultaneous system. He emphasized that without defining the statistical properties of all the variables involved, we cannot know the meaning of the statistical results obtained by fitting separate equations to the data. The problem, in brief, can be described as follows:[1]

In a production system the production function is not an isolated relation. Data observations are generated by profit maximizing (or cost minimizing) considerations of the firm and thus the output and input levels are simultaneously determined. The production function is only one of a system of simultaneous equations and single equation estimates are in general biased and inconsistent. In dealing with problems originating from the simultaneous nature of determination of the outputs and inputs in production systems, the first major thrust was the important paper of Marschak and Andrews (July-October 1944). They place special emphasis on management to explain differences among firms and split these differences into those due to differences in the production functions (technical efficiency) and those due to differences in abilities to maximize profits (economic efficiency) among firms. By imposing restrictions it is possible to restrict parameter estimates of the Cobb-Douglas production function to narrow ranges, but unique estimates are still not possible.

Subsequently the analysis of covariance approach using combined time-series and cross-section data has been suggested by Hoch (July 1955), but this approach cannot be used in a single cross-section. In another paper (October 1958), Hoch advances a more serious criticism of

---

[1]For this and other related problems see Walters (January-April, 1963), survey article on "Production and Cost Functions."

single-equation least-squares estimates in the Cobb-Douglas case. He showed that, under the assumption that disturbances in various equations of the system are independently distributed but that the error term of the production function is related to independent variables, the sum of the estimated coefficients has a pronounced tendency towards a sum of one regardless of the true sum. This tendency, however, is not so apparent if the assumption of independence of the error terms is dropped. But in that case, single equation estimation procedures are not valid. Hoch argued further that, when variable input levels are determined for the current period by maximizing with respect to anticipated output, the disturbance in the production function affects only output and not the other variables and so the simultaneous equation bias may not be serious.

Griliches (May 1963), and Mundlak and Hoch (October 1965) also expressed similar views. Griliches argued that, because inputs in agriculture are largely predetermined because of a considerable lag in production and error being largely weather determined, simultaneous equation bias will be small for well specified production functions. Mundlak and Hoch (Section 3, Case B) argued in a similar vein. They argued that, at the time of application of inputs, the disturbance is unknown to the producer in view of the lag between input application and the realization of output and thus, the assumption that error term in production function is equal to one is justifiable and that least-squares estimators are consistent.

For a stochastic production function of the Cobb-Douglas type Zellner, Kmenta and Dreze (October 1966) argued that for non-instantaneous production processes, "... the effect of the disturbance on output cannot be known until after the preselected quantities of inputs have been employed in production." They assumed that (i) entrepreneurs maximize mathematical expectation of profit, i.e., they are aware of the stochastic nature of production, (ii) input prices are either known with certainty or statistically independent of the production function disturbance, and show that inputs are independent of the disturbance in the production function. They further argued that disturbances in the production function arise largely from "acts of nature" and those in the profit-maximizing equations due to "human errors," and are thus uncorrelated; that simple least-squares estimators with these assumptions are consistent and that under normality, or with stronger assumptions, they are also unbiased.

The production environment in the present study does not seem to be any different from the specification requirements of the studies referred to above. Our production function is thus well specified and we take it that there is no problem of identification. Nevertheless, subsequently we develop Cost Function and Profit Function Models, the two alternative approaches which are free from the ~~simultaneous~~ single equation bias problem, and compare the results.

Another difficulty in production function studies is that some variables (management, for example) cannot be included in the analysis. Griliches (February 1957) showed that in a Cobb-Douglas framework returns to scale are underestimated if the excluded input varies less than proportionately with the included inputs and <u>vice versa</u>, and that exclusion of management imparts an upward bias to the capital coefficient and downward bias to the returns to scale. Mundlak (February 1961) also shows that exclusion of management results in biased estimates of the production function parameters. He demonstrates that covariance analysis can be used on two year cross-section data to obtain unbiased estimates. Mundlak also suggests that awareness that management (the left out variable) is correlated with other inputs is helpful in interpreting the results.

Cost Function Model

The production model developed in the previous section does not permit us to obtain estimates of long-run cost function or to make direct comparisons of the shifts in the cost functions of old and new wheats. For this purpose we will use a cost function model first used by Nerlove (1965, Chapter 6) with slight modifications.

Let

(2.3) $C = wN + tL + iK$ be the total cost of production where

C = total production costs in rupees

w = hourly wage rate of labor

t = per acre rent of land for wheat

i = price of capital

N = labor input in hours

L = acres of land, and

K = capital input

Minimization of costs (2.3) subject to the Cobb-Douglas production function (2.2) yields the following marginal productivity conditions:

(2.4) $$\frac{wN}{\alpha_1} = \frac{tL}{\alpha_2} = \frac{iK}{\alpha_3}$$

The derived input demand functions for N, L and K can be obtained by simultaneously solving the marginal productivity conditions (2.4) and the production function (2.2):

(2.5) $$N = \beta_1 \, Y^{\frac{1}{\gamma}} \frac{w^{\frac{\alpha_1}{\gamma}} \, t^{\frac{\alpha_2}{\gamma}} \, i^{\frac{\alpha_3}{\gamma}} \, e^{-\left(\frac{\delta+u}{\gamma}\right)}}{w}$$

(2.6) $$L = \beta_2 \, Y^{\frac{1}{\gamma}} \frac{w^{\frac{\alpha_1}{\gamma}} \, t^{\frac{\alpha_2}{\gamma}} \, i^{\frac{\alpha_3}{\gamma}} \, e^{-\left(\frac{\delta+u}{\gamma}\right)}}{t}$$

(2.7) $$K = \beta_3 \, Y^{\frac{1}{\gamma}} \frac{w^{\frac{\alpha_1}{\gamma}} \, t^{\frac{\alpha_2}{\gamma}} \, i^{\frac{\alpha_3}{\gamma}} \, e^{-\left(\frac{\delta+u}{\gamma}\right)}}{i}$$

where $$\beta_j = \alpha_j \left(A \, \alpha_1^{\alpha_1} \, \alpha_2^{\alpha_2} \, \alpha_3^{\alpha_3}\right)^{-\frac{1}{\gamma}} \qquad j = 1, 2, 3$$

and $$\gamma = \alpha_1 + \alpha_2 + \alpha_3.$$

The total cost function can now be obtained[1/] by substituting (2.5), (2.6) and (2.7) for N, L and K respectively in the cost equation (2.3):

[1/] The procedure followed for this derivation is essentially that of Nerlove (1965, Chapter 6). Also see Heady (1961, pp. 11-14), Heady and Dillon (1966, pp. 59-64), Henderson and Quandt (1971, Chapter 3) and Johnston (1960, Chapter 2) for some variants of this procedure.

(2.8) $$C = \beta\, Y^{\frac{1}{\gamma}}\, w^{\frac{\alpha_1}{\gamma}}\, t^{\frac{\alpha_2}{\gamma}}\, i^{\frac{\alpha_3}{\gamma}}\, e^{-\left(\frac{\delta+u}{\gamma}\right)}$$

where

$$\beta = \beta_1 + \beta_2 + \beta_3 = \gamma \left(A\, \alpha_1^{\alpha_1}\, \alpha_2^{\alpha_2}\, \alpha_3^{\alpha_3}\right)^{-\frac{1}{\gamma}} .$$

Let the cost function (2.8) be written in logarithms of the variables:

(2.9) $$\ln C = \ln \beta + \frac{1}{\gamma} \ln Y + \frac{\alpha_1}{\gamma} \ln w + \frac{\alpha_2}{\gamma} \ln t + \frac{\alpha_3}{\gamma} \ln i - \frac{\delta}{\gamma} - \frac{u}{\gamma}$$

which forms the basic estimating equation for this model.

There are several points to be noted about this model. The parameter γ provides a direct single estimate of returns to scale as a reciprocal of the coefficient of logarithm of Y, which is independent of the level of output and input prices. This is a considerable advantage. At the same time the invariance of γ with respect to output level does not permit us to ascertain whether the degree of returns to scale varies over various ranges of output.[2/] This difficulty can, however, be overcome by dividing the total observations into several

---

[2/] See Heady (1964, pp. 364-9) for long-run cost possibilities in agriculture. He argues that agriculture is perhaps characterized by first falling, then constant over some range of output, but ultimately increasing long-run average costs. For an excellent discussion which explains the existence and observed wide range of firm sizes under increasing returns to scale see Lydall (March 1971). In his argument the existence of a falling long-run cost curve instead of telling what is available to all potential firms tells what may be available at each point along the curve to a firm which is already nearly at that point. In other words expansion to the next size requires learning and experience. His point is developed primarily for the nonagricultural sector where he assumes economies of scale to be pervasive. It should be equally applicable to the agricultural sector if in fact economies of scale exist in some output range.

groups and fitting separate functions or by introducing $(\ln Y)^2$ as an additional term in model (2.9). In our empirical analysis, both techniques are used.

Secondly, the inclusion of input prices directly in the cost function helps us to obviate some usual problems with statistical estimation of long-run cost functions. We don't need to deflate cost figures cross-sectionally or over the four-year period studied. Unique correspondence between the empirically estimated cost function and the underlying production function is assured,[1/] that is the parameters of the production function can easily be evaluated. Furthermore since all our independent variables in model (2.9) are exogenous its coefficients can appropriately be estimated by least squares, that is, there is no problem of identification.[2/]

$(\frac{\delta}{\gamma})$ in (2.9) can be interpreted as coefficient(s) of the dummy variable(s) which can be introduced to compare neutral differences in cost functions of old and new wheats and overtime.

For purposes of empirical estimation, model (2.9) has to be further amended. This is necessary because data on capital price i is not available for individual farms. We can write (2.9) as:

[1/] See Shephard (1953, 1970) and Uzawa (May 1964) for the 'fundamental duality' between the cost and production functions.

[2/] Much, however, depends upon the authenticity of input price data. To the extent interfarm price variations reflect input qualities rather than true price variations due to location and time, our estimates may be defective. This could be a more serious problem with land rent which in spite of being determined competitively may include land quality component.

$$(2.10) \qquad \ln C = \beta^* + \frac{1}{\gamma} \ln Y + \frac{\alpha_1}{\gamma} \ln w + \frac{\alpha_2}{\gamma} \ln t - \frac{\delta}{\gamma} - \frac{u}{\gamma}$$

where $\qquad \beta^* = \ln \beta + \frac{\alpha_3}{\gamma} i.$

Since $\gamma = \alpha_1 + \alpha_2 + \alpha_3$, α_3 the output elasticity with respect to capital input can be evaluated from this restriction. The elimination of capital price i from the model, however, causes some specification problem (Griliches, 1957) and imparts biases to the coefficients of the remaining variables. In particular, based on our discussion of likely imperfection in the capital market, it can be argued a priori that output Y and capital price i have a negative correlation. This imparts a downward bias to $(\frac{1}{\gamma})$ the estimated coefficient for logarithm of output, and thus an upward bias to γ the measure of returns to scale. This is a weakness of the model in the sense that the estimated output elasticities with respect to various inputs and the measure of returns to scale are not reliable estimates.

Profit Function Model

The recently developed theory of profit functions has made available to us an alternative approach which helps overcome the problem of simultaneous equation bias if present and provides answers to the remaining or other questions.

The theory and applications of profit function approach have been developed at length by Lau and further used by Lau and Yotopolous[1/] in

[1/] The concept of profit function is reported to be first introduced by D. L. McFadden; "Cost, Revenue, and Profit Functions" in a forthcoming book, The Econometric Approach to Production Theory, ed. D. L. McFadden. Having not seen this article, my work is based on the five references by Lau and Lau and Yotopoulous cited in the first paragraph of this chapter, page 8.

analyzing Indian agriculture. We are not interested in the theoretical details of their work. An operational model is constructed to provide answers as well as possible for the purpose of this study. The procedure is, first, to provide the bare essentials of profit function theory and its assumptions, and then to develop a Cobb-Douglas version applicable to wheat production. Appropriate estimating equations are then developed.

To start with, let the production function (2.1) be written as:

$$(2.11) \qquad Y = F\ (N;\ L,\ K)$$

where Y is output, N is labor, the variable input, and L and K the fixed inputs of land and capital respectively. The production function is assumed to be concave in N, continuous and increasing in N, L, and K, twice differentiable in N and once differentiable in L and K.[1/]

The profit P, from wheat production is equal to total revenue minus total variable labor costs:

$$(2.12) \qquad P = p.F\ (N;\ L,\ K) - w\ N$$

where p is wheat price and w the wage rate.

[1/] These assumptions are necessary to insure the existence of a unique, optimal solution to the profit maximizing problem and consequently the existence of single-valued supply and derived demand functions as continuously differentiable functions of normalized wage rate, L and K.

The profit maximizing conditions for this case imply,

(2.13) $$p \cdot \frac{\partial F\ (N;\ L,\ K)}{\partial N} = w$$

(2.14) $$\text{or } \frac{\partial F}{\partial N} = w' \quad \text{where}$$

$w' \equiv \frac{w}{p}$ is the normalized wage rate.

Also (2.12) can be written as:

(2.15) $$P^* = \frac{P}{P} = F\ (N;\ L,K) - w'\ N$$

small p

which, in the language of Lau and Yotopoulos (Feb. 1972), is called the 'Unit-Output-Price' profit or UOP profit.

Solving the marginal productivity condition (2.14) for N^*, the optimal quantity of labor, as a function of the normalized wage rate and quantities of L and K gives:

(2.16) $$N^* = f\ (w',\ L,K).$$

Substituting (2.16) into the profit equation (2.12) we get the profit function:[1/]

(2.17) $$\pi = p.\ [F(N^*;\ L,K)] - w'\ N^*$$

which gives a maximized value of profit for each set of values {p,w , L, K}. Since N^* is a function of w', L and K from (2.16), we can write (2.17) as:

[1/] Since land and capital are treated as fixed inputs, Lau and Yotopoulos (Feb. 1972) refer to it as the partial profit function.

(2.18) $$\pi = p\ g^{*}\ (w';\ L,K)$$

which gives the UOP profit function:

(2.19) $$\pi^{*} = \frac{\pi}{p} = g^{*}\ (w';\ L,K)$$

which is decreasing and convex in w' and increasing in p and the quantities of L and K. It is continuous in w', L and K; twice differentiable in w' and once differentiable in L and K.[1/]

Lau and Yotopoulos (Feb. 1972), based on what they call Shepard's Lemma[2/]--which provides a set of dual transformation relations connecting the production function and the profit function[3/]--derive the supply and factor demand functions from the UOP profit function. Following their approach, the labor demand function N^{*} and supply function Y^{*} can be written as (2.20) and (2.21) respectively.

(2.20) $$N^{*} = -\frac{\partial \pi^{*}(w',\ L,K)}{\partial\ w'}$$

(2.21) $$Y^{*} = \pi^{*}\ (w',\ L,K) - \frac{\partial\ \pi^{*}\ (w',L,K)\ w'}{\partial\ w'}$$

For purposes of this research the labor demand function (2.20) and the output supply function (2.21) are of crucial importance. A tremendous advantage of the profit function approach is that with the help of duality theorem and the conditions stipulated above for the UOP profit function (2.19), the functions (2.20) and (2.21) can be directly derived.

1/ See Lau (Memorandums 86A and 86B) for these results.

2/ Shephard (1953).

3/ These relations are proved in references cited in footnote 1 above.

Another distinct advantage of this approach, inter alia,[1] is that it is normal to assume the influencing variables w', L and K as exogenous. This should help overcome the simultaneous equation bias if present.[2]

The system (2.19), (2.20), and (2.21) can be cast in a Cobb-Douglas framework and estimation equations developed. But this basic model needs to be further extended in order to answer a wider range of questions, particularly those related to farm size efficiency.

Farm size efficiency of Indian agriculture has been extensively studied and debated.[3] Data used in these discussions came mostly from the mid-fifties when Indian agriculture was relatively static or closer to Schultz's (1964) traditional agriculture. There appeared to be a consensus about the existence of constant returns to scale in Indian agriculture. There does not seem to be a similar consensus on whether

---

1/ These advantages are spelled out in detail in Lau and Yotopoulos, (February, 1972).

2/ There is some problem here though. The capital input K includes fertilizer costs in it. It would be more normal to treat fertilizer as a variable input of production. This, however, is impossible in the above formulation because of the institutionally determined uniform level of fertilizer prices.

3/ See for instance Sen (January, 1962; May 2, 1964; February, 1964), Mazumdar (July, 1963), Agarwala (April 11, 1964; and November 21, 1964) and Bardhan, K (August 22, 1964) for articles in Economics Weekly; and Khusro (October, 1964), Mazumdar (May, 1965), Sen (October, 1968), Paglin (September, 1965; March, 1967), Bennett (March, 1967), Sahota (August, 1968), Hopper (1965), Lau and Yotopoulos (February, 1972; March, 1971, Memorandum 104), Rudra (July, 1968; and October, 1968), Sanyal (August, 1969), and Saini (June, 1969; and June, 1971). Also see Bhagwati and Chakravarty (Sept. 1969) for a summary of most of the researches prior to 1969.

relatively smaller or larger farms are economically more efficient. Researches by Lau and Yotopolos indicate that smaller farms are relatively more economic efficient[1/] and that this is due to their being technically[1/] more efficient--both types of farms being equally and absolutely price-efficient.[1/] The technique they have used to decompose economic efficiency into technical and price efficiency lends itself to simple manipulation with some further extensions of the above model. It is important that this model be confronted with new and recent data, in order to verify their conclusions for wheat farms of Punjab and to compare the efficiency of tractor versus non-tractor farms.[2/]

In order to study relative economic efficiency let us start by rewriting the production function (2.11) for two farms (1,2) as follows:

$$(2.22) \qquad Y^1 = A^1 F(N^1; L^1, K^1); \qquad Y^2 = A^2 F(N^2; L^2, K^2)$$

where management, some intangible inputs or environmental differences

---

[1/] Subsequently these concepts are given specific meaning.

[2/] In Indo-Pakistan wheat growing areas the introduction of high-yielding wheat varieties appears to have shifted the demand for labor rightward. This is being reflected both in increased demands for labor and labor-saving technology, tractors in particular. Thus, the point whether there exist any technological gains from tractor farming is of great importance. If in fact there are no such extra gains, the shifts in labor demand could be exploited for better employment opportunities by restricting a faster growth of labor-saving types of technologies which may not be in the best interests of these countries. See for example Krishna (September, 1969), Johnston and Cownie (September, 1969), Kaneda (1969), Shaw (1970), and Falcon (December, 1970) among others warning about the consequences of labor-saving technologies in the context of "Green Revolution." For an opposite view see Johl (1971).

could create neutral differences in the technical efficiency parameters A^1 and A^2 of the two farms.

Let us also rewrite the marginal productivity condition (2.14) for these two farms (1,2) as below:

$$(2.23) \quad \frac{\partial A^1 F(N^1; L^1, K^1)}{\partial N} = k^1 w'^1; \quad \frac{\partial A^2 F(N^2; L^2, K^2)}{\partial N} = k^2 w'^2$$

$$k^1 \geqq 0 \qquad\qquad k^2 \geqq 0$$

The meaning of (2.23) is that the two farms may not be attaining price or allocative efficiency in the sense of maximizing profits by equating the marginal product of labor to the going normalized wage rate w' and may be unequally inefficient. They may in fact be operating upon their own firm-specific (or effective) wage rate,[1/] which is simply a firm-specific constant k, times the ruling normalized wage rate.

If the two farms are equally price efficient with respect to the input of labor, then $k^1 = k^2$, and they maximize profits if $k^1 = k^2 = 1$. In other words, for two firms, with equal technical efficiency and facing identical input and output prices, differences in k's represent differences in managerial-entrepreneurial ability.

[1/] Lau and Yotopoulos (March, 1971, p. 99) provide several reasons for this: "(1) Consistent over-or under-valuation of the opportunity costs, (2) Satisficing behavior; (3) Divergence of expected and actual normalized prices; (4) Divergence of the subjective probability distribution of the normalized prices from the objective distribution; ...." Also see Bhagwati and Chakravarty (Sept. 1969) for a summary of the viewpoints of Sen, Khusro, Mazumdar and Rao as to why small family farms evaluate their family labor at less than the going wage rates. For more recent attempts to explain this point see Srinivasan (Jan. 1971) and Bardhan (1972).

Technical efficiency of the two farms would be equal if the farm specific efficiency parameters A^1 and A^2 in (2.22) are equal.[1/] If and only if $A^1 = A^2$ and $k^1 = k^2$ would the actual UOP profit functions and the labor demand functions of the two farms coincide with each other. Economic efficiency thus comprises of its two components: technical efficiency and price efficiency. A more technical efficient firm than another produces larger output from given quantities of inputs. A firm is price efficient if it maximizes profits by equating the marginal value product of variable inputs to their prices. But firms could be price inefficient (and to varying degrees) if they are unable to maximize profits. Thus differences in economic efficiency could originate in differences in their technical efficiency, price efficiency or both. It may be noted that the two farms can have equal economic efficiency with varying degrees of technical and price efficiency. Our purpose now is to develop a method to make these comparisons.

Following Lau and Yotopoulos (March 1971; and Memorandum 104), (2.19) may be written as the behavioral UOP profit functions for the two farms corresponding to their production functions (2.22) as:

$$(2.24) \qquad \pi^{*i} = A^i g^* (k^i w'^i / A^i;\ L^i,\ K^i) \qquad i = 1,2$$

[1/] See also Nerlove (1965), Hoch (July, 1955). Timmer (July-Aug. 1971), Farrell (1957) and Seitz (Nov. 1970) are three other approaches for measuring technical efficiency.

The actual labor demand and supply functions corresponding to (2.20) and (2.21) now are (2.25) and (2.26) respectively:

$$(2.25) \qquad N^{*i} = -A^i \frac{\partial g^*(k^i w'^i / A^i; L^i, K^i)}{\partial (k^i w^i)}$$

$$= -\frac{A^i}{k^i} \frac{\partial g^*(k^i w'^i / A^i; L^i, K^i)}{\partial w^i} \qquad i = 1,2$$

$$(2.26) \qquad Y^{*i} = A^i g^*(k^i w'^i / A^i; L^i, K^i) - A^i k^i w'^i \frac{\partial g^*(k^i w'^i/A^i; L^i, K^i)}{\partial k^i w'^i}$$

$$= A^i \left[g^*(k^i w'^i/A^i; L^i, K^i) - w'^i \frac{\partial g^*(k^i w'^i/A^i; L^i, K^i)}{\partial w^i} \right]$$

$$i = 1,2$$

N^{*i} and Y^{*i} in (2.25) and (2.26) are the actual quantities of labor demanded and output supplied by farm i given farm-specific A^i and k^i. From these actual demand and supply functions we can obtain the actual <u>UOP profit functions</u> (2.27).

$$(2.27) \qquad \pi^{*i} = Y^{*i} - w'^i N^{*i}$$

$$= A^i \left[g^*(k^i w'^i/A^i; L^i, K^i) + \frac{(1-k^i) w'^i}{k^i} \frac{\partial g^*(k^i w'^i/A^i; L^i, K^i)}{\partial w^i} \right]$$

$$i = 1,2.$$

It should be noted that because of profit identity in empirical analysis only two of the three functions (2.25), (2.26) and (2.27) need be estimated. We will <u>subsequently work only with (2.25) and (2.27).</u>

The Cobb-Douglas Framework

Let the Cobb-Douglas production function (2.2) be rewritten with decreasing returns in labor input as:

$$(2.28)\qquad Y = A\, N^{\alpha_1} L^{\alpha_2} K^{\alpha_3}$$

where $\alpha_1 < 1$.

For (2.28) the UOP profit function is given by:[1/]

$$(2.29)\qquad \pi^* = A^{(1-\alpha_1)^{-1}} (1-\alpha_1)\left(\frac{w'}{\alpha_1}\right)^{-\alpha_1 (1-\alpha_1)^{-1}} L^{\alpha_2(1-\alpha_1)^{-1}} K^{\alpha_3(1-\alpha_1)^{-1}}$$

which can be written in natural logarithms of the variables as:

$$(2.30)\qquad \ln \pi^* = \ln A^* + \beta_1 \ln w' + \beta_2 \ln L + \beta_3 \ln K$$

where

$$A^* \equiv A^{(1-\alpha_1)^{-1}} (1-\alpha_1)\, \alpha_1^{\alpha_1(1-\alpha_1)^{-1}}$$

$$\beta_1 \equiv -\alpha_1 (1-\alpha_1)^{-1} < 0$$

$$\beta_2 \equiv \alpha_2 (1-\alpha_1)^{-1} > 0$$

$$\beta_3 \equiv \alpha_3 (1-\alpha_1)^{-1} > 0$$

[1/] Production function (2.28) and the profit maximizing equations for labor can be solved for the optimal quantity of labor N^*. The UOP profit function (2.29) is obtained by direct computations by substituting N^* in the UOP profit equation (2.15): $P^* = Y - w'N$.

If we multiply both sides of the labor demand function (2.20) by $-w'/\pi^*$ we get:

$$(2.31) \qquad -\frac{w'N^*}{\pi^*} = \frac{\partial\ \pi^*}{\partial\ w'} \cdot \frac{w'}{\pi^*} = \frac{\partial\ \ln\ \pi^*}{\partial\ \ln\ w'}$$

which for the Cobb-Douglas UOP profit function (2.30) becomes:

$$(2.32) \qquad -\frac{w'\ N^*}{\pi^*} = \beta_1.$$

Equations (2.30) and (2.32) are the basic estimating forms. Since β_1 appears in both the UOP profit function and the labor demand function, the two functions are estimated jointly and the restriction that β_1's in the two equations are equal is imposed.

For the purpose of studying relative economic efficiency (2.27) can be written as the actual UOP profit function for farm i with efficiency parameter A^i and the farm and labor specific parameter k^i. For the Cobb-Douglas production function (2.28) it is given by:

$$(2.33) \qquad \pi^{*i} = A^{i^{(1-\alpha_1)^{-1}}} (1-\alpha_1/k^i)(k^i)^{-\alpha_1(1-\alpha_1)^{-1}} \alpha_1^{\alpha_1(1-\alpha_1)^{-1}}$$

$$(w'^i)^{-\alpha_1(1-\alpha_1)^{-1}} (L^i)^{\alpha_2(1-\alpha_1)^{-1}} (K^i)^{\alpha_3(1-\alpha_1)^{-1}} \qquad i = 1,2$$

or

$$(2.34) \qquad \pi^{*i} = A_*^i (w'^i)^{\beta_1} (L^i)^{\beta_2} (K^i)^{\beta_3} \qquad i = 1,2$$

where

$$A_*^i \equiv A^{i^{(1-\alpha_1)^{-1}}} (1-\alpha_1/k^i)(k^i)^{-\alpha_1(1-\alpha_1)^{-1}} \alpha_1^{\alpha_1(1-\alpha_1)^{-1}} \qquad i = 1,2$$

$$k_*^i \equiv (1-\alpha_1/k^i)(1-\alpha_1)^{-1} \qquad i = 1,2$$

$$\beta_1 \equiv -\alpha_1(1-\alpha_1)^{-1} < 0$$

$$\beta_2 \equiv \alpha_2(1-\alpha_1)^{-1} > 0$$

$$\beta_3 \equiv \alpha_3(1-\alpha_1)^{-1} > 0$$

And the labor demand function for farm i is given by:[1/]

$$(2.35) \qquad N^{*i} = A^{i^{(1-\alpha_1)^{-1}}} (\alpha_1/k^i w'^i)\,(k^i)^{-\alpha_1(1-\alpha_1)^{-1}} \alpha_1^{\alpha_1(1-\alpha_1)^{-1}} (w'^i)^{-\alpha_1(1-\alpha_1)^{-1}} (L^i)^{\alpha_2(1-\alpha_1)^{-1}} (K^i)^{\alpha_3(1-\alpha_1)^{-1}} \qquad i = 1,2$$

or

$$2.36) \qquad N^{*i} = -A_*^i\,\beta_1\,(k^i)^{-1}\,(w'^i)^{-1}\,(k_*^i)^{-1}\,(w'^i)^{\beta_1}\,(L^i)^{\beta_2}\,(K^i)^{\beta_3} \qquad i = 1,2$$

or, by substitution from (2.34)

$$(2.37) \qquad -\frac{w'^i N^{*i}}{\pi^{*i}} = (k^i)^{-1}\,(k_*^i)^{-1}\,\beta_1 \equiv \beta_1^i \qquad i = 1,2$$

[1/] The labor demand function (2.35) is obtained by direct computations from the production function (2.28) and the marginal productivity condition for labor.

Equations (2.34) and (2.37) indicate that the actual UOP profit functions and the labor demand functions of the two farms differ only by constant factors which are functions of A^i and k^i. Thus in order to compare the relative efficiency of the two farms we have to compare the magnitudes of A^i's and k^i's.

If in (2.34) for farms 2 and 1 we write A_*^2 and A_*^1 for A_*^i we can rewrite (2.34) as (2.38) and (2.39)

$$(2.38) \qquad \pi^{*1} = A_*^1 \; (w'^1)^{\beta_1} \; (L^1)^{\beta_2} \; (K^1)^{\beta_3}$$

$$(2.39) \qquad \pi^{*2} = A_*^1 \; (A_*^2/A_*^1) \; (w'^2)^{\beta_1} \; (L^2)^{\beta_2} \; (K^2)^{\beta_3}$$

And taking natural logarithms of (2.38) and (2.39) we have

$$(2.40) \qquad \ln \pi^{*1} = \ln A_*^1 + \beta_1 \ln w'^1 + \beta_2 \ln L^1 + \beta_3 \ln K^1$$

$$(2.41) \qquad \ln \pi^{*2} = \ln A_*^1 + \ln (A_*^2/A_*^1) + \beta_1 \ln w^2 + \beta_2 \ln L^2 + \beta_3 \ln K^3$$

Maintaining the hypothesis that there are no non-neutral differences in the technologies of the two farms, for empirical estimation (2.41) and (2.37) can be rewritten as (2.42) and (2.43) respectively:

$$(2.42) \qquad \ln \pi^* = \ln A_*^S + \delta^L D^L + \beta_1 \ln w + \beta_2 \ln L + \beta_3 \ln K$$

$$(2.43) \qquad -\frac{w' N}{\pi^*} = \beta_1^L D^L + \beta_1^S D^S$$

where L and S stand for large and small farms respectively, $\delta^L \equiv \ln (A_*^L/A_*^S)$, and D^L and D^S are dummy variables taking the value of one for large[1/] and small farms respectively and zero otherwise.

[1/] In this study farms with more than 10 acres of wheat are defined as large farms and farms with 10 acres or less as small farms. This

For Equal relative economic efficiency $A_*^L = A_*^S$ or $\delta^L = \ln(A_*^L/A_*^S) = 0$. For equal relative price efficiency $\beta_1^L = \beta_1^S$ in (2.43), and for absolute price efficiency of large farms and small farms respectively $\beta_1 = \beta_1^L$ and $\beta_1 = \beta_1^S$. When we analyze and compare tractor operated (T) versus non-tractor operated (NT) farms D^L and D^S in equations (2.42) and (2.43) will be replaced by D^T and D^{NT} respectively with no other change involved. D^T and D^{NT} will take the value of 1 for tractor and non-tractor farms and zero otherwise.

Output price p of wheat is government supported at uniform level throughout the state. This helps to further simplify equations (2.42) and (2.43) as follows:

$$(2.44) \quad \ln \pi^* = \ln \pi - \ln p = \ln A_*^S + \delta^L D^L + \beta_1 \ln w - \beta_1 \ln p + \beta_2 \ln L + \beta_3 \ln K$$

or

$$\ln \pi = \ln A_*^S + \delta^L D^L + (1-\beta_1) \ln p + \beta_1 \ln w + \beta_2 \ln L + \beta_3 \ln K$$

where π is actual money profit, w the money wage rate per hour and p the output price.

For the case when four years (1967/68 to 1970/71) data are analyzed, year dummies can be introduced to capture the effects due to $(1-\beta_1) \ln p$ and weather, etc. and rewrite (2.44) as:

---

seems to be quite realistic dividing line between large and small wheat farms for Punjab where the average farm size is 12.5 acres (Singh and Billings, January 1971). Also it facilitates comparisons of our results with those of Lau and Yotopoulos (March 1971 and Memorandum 104) who use this criterion for small and large farms.

$$(2.45) \quad \ln \pi = \ln A_*^S + \delta^L D^L + \sum_{i=1}^{3} \delta i Di + \beta_1 \ln w + \beta_2 \ln L + \beta_3 \ln K$$

where

D_1, D_2, D_3 are the year dummies with the value of 1 for 1968/69, 1969/70, 1970/71 respectively and zero otherwise.

But for the individual years we have to write (2.44) as:

$$(2.46) \quad \ln \pi = \lambda + \delta^L D^L + \beta_1 \ln w + \beta_2 \ln L + \beta_3 \ln K$$

where

$$\lambda = \ln A_*^S + (1-\beta_1) \ln p,$$

from which $\ln A_*^S$ can be evaluated at $(\overline{\ln p})$ for the sample.

Equation (2.46) can be estimated with or without a farm size dummy. Without the dummy we write it as:

$$(2.47) \quad \ln \pi = \lambda + \beta_1 \ln w \pm \beta_2 \ln L + \beta_3 \ln K.$$

The labor demand equation (2.43), however, holds independently of the price of output and can be written as:

$$(2.48) \quad -\frac{w' N}{\pi^*} = -\frac{w N}{\pi} = \beta_1^L D^L + \beta_1^S D^S$$

In recapitulation we have three systems of two equations each as our three models as below:

Model I: Equations (2.47) and (2.32) constitute our model I. They are estimated jointly and since β_1 appears in both equations we impose the restriction that it be equal in the two equations. This model is used to compare efficiency of old and new wheats and to obtain various elasticity measures.

For purposes of comparative efficiency studies we have models II and III as follows:

Model II: Equations (2.46) and (2.48): used for comparing efficiency of small and large farms and tractor and non-tractor farms and to obtain various elasticity measures.

Model III: Equations (2.45) and (2.48): used for comparing efficiency of small and large farms and to obtain various elasticity estimates from the pooled data over four years.

Again in models II and III the restrictions that $\beta_1 = \beta_1^L$ and $\beta_1 = \beta_1^S$ are imposed.

For statistical specification of these models following Lau and Yotopoulos (March 1971, Feb. 1972 and Memorandum 104) we assume an additive error with zero expectation and finite variance for each of the two equations in all three models. The covariance of the errors of the two equations for the same farm may not be zero but the covariances of the errors of either equation corresponding to different farms are assumed to be zero. With these assumptions an asymptotically efficient method of estimation as proposed by Zellner (June 1962) is used.[1/]

In terms of the objectives of this study additional gains by working with the profit function technique are as follows:

[1/] This will also make our results comparable to those of Lau and Yotopoulos as reported in the above references.

(i) Various output supply elasticities and labor demand elasticities crucial for policy decisions can be directly obtained by differentiation of the logarithmic output supply and labor demand functions.

(ii) Conceptually, the indirect estimates of the input elasticities of the Cobb-Douglas production function derived from the side relations (identities) in (2.30) and (2.34) are statistically consistent.

(iii) Operationally simple and straightforward criteria are available to compare differing sources of efficiency among farm groups.

(iv) Rates of return to the fixed factors of production land and capital can be easily obtained for the mean (or any other) level of use.

(v) A very simple test for testing returns to scale <u>in all inputs</u> (Lau and Yotopoulos, Feb. 1972), is available. It is equivalent to testing whether the sum of the elasticities of the profit function with respect to fixed factors of land L and capital K is equal to one i.e., the hypothesis $\beta_2 + \beta_3 = 1$.

CHAPTER III

THE DATA, THE REGION AND THE VARIABLES

The purpose of this chapter is to describe and identify the nature, sources and converage of data used in this study and to provide a brief description of the area to which the investigation pertains. The underlying assumptions, sampling procedures, methods of data collection and construction of variables are examined, with a view to placing the findings of this study in proper perspective. This is important since most analyses of Indian agriculture have expressed reservations about the quality of earlier data. Because of the nature of the investigation we need farm level primary data. Such cross-sectional data for the four years 1967/68 to 1970/71 form the basis of this study.

Samples and Sources

The three different samples which form the data base of this study have somewhat different geographic coverages and also differ in terms of size and purposes of stratification. Each is discussed briefly.

Ferozepur Sample

This sample has a coverage of 150 farms spread over 15 villages for the years 1967/68 and 1968/69, in the district of Ferozepur (FZR) which forms the southwestern part of Indian Punjab. This district has approximately 20 percent of the total area as well as 20 percent of the total cropped area of the state.[1/] During the year 1967/68 wheat production in the district was 21.38 percent of the total wheat production in Punjab.[2/] This sample thus constitutes a fairly representative situation for the state.

The Directorate of Economics and Statistics (Ministry of Food and Agriculture, Government of India) collected data on these 150 farms for all farm enterprises for the crop years 1967/68 to 1969/70, for Studies in Economics of Farm Management in Ferozepur District of Pnnjab. Wheat data forms only a part of these data and was copied from their records.[3/]

The sample itself can be characterized as a "Multi-stage Stratified Random Sample." For the selection of farms, three steps were involved, after the selection of the district. First the district was demarcated into three relatively homogeneous zones with respect to soil-crop complex. Second, a total of fifteen villages was selected in the district, such that the number of villages in each zone was proportional to its cultivated area, and the villages in each zone being selected at random with the probability of each proportional to its cultivated area. Third, for the selection of cultivators, a consolidated list

---

[1/] Economic Adviser to Government of Punjab (Jan. 1971, pp. 10, 65).

[2/] See A.S. Kahlon, S.S. Miglani and S.K. Mehta, "Report for 1968/69," p. 8.

[3/] The data for 1969/70 from this sample have not been available for purposes of this study. For the first two years, however, data for both "Old" and "New" wheats have been made available. The number of observations for each kind of wheat is reported in Table 3.2.

of all farms in the selected fifteen villages was prepared in ascending order of their cultivated area, and divided into five classes, with each class having equal total cultivated area. Two farms were selected from each class in each village, thus giving 10 farms in each village and 150 farms in the district.

The recording of data on 10 farms was done by a trained investigator through daily visits to the farms by what is commonly referred to as 'Cost Accounting Method.' For subsequent discussion this sample will be referred to as 'FZR Sample.'

Tractor Cultivation Sample

This sample is larger than FZR Sample, both in terms of number of farms and its geographic coverage. Also it has a wider range both in terms of land area and output per farm. It covers the crop year 1969/70.

There is a total of 304 farms in this sample. These farms are spread practically over the whole of Punjab in 19 villages with 16 farms in each village. Six farms out of 16 in each village owned and operated tractors. So this sample can be used for somewhat wider purposes. The sampling design for this sample also was "Multi-stage Stratified Sampling." The data collection work was carried out essentially as in case of FZR Sample, by "Cost Accounting Method." The data were made available from their files through the courtesy of the Economic Adivser to the Government of Punjab. As in the case of FZR Sample, the wheat data were only a part of the data collected for all enterprises. The basic purpose of the sampling design was to study effects of tractor cultivation in Punjab farming. For future reference the sample will be called "TC Sample."

Regionally Stratified Sample

As suggested in Appendix I, agroclimatic regions (ii), (iii) and (iv) are relatively more important for wheat production in Punjab. These regions have some distinctive features--for example, annual rainfall and soil profile. A regionally stratified sample was designed to determine whether these differences affect the underlying production transformation relationship for wheat.[1/] A total of 128 farms was studied during the crop year 1970/71--46 in zone (ii), 31 in zone (iii) and 51 in zone (iv). The number of farms in each zone is roughly proportional to the wheat area in that zone. In consultation with Soils Department Staff at Punjab Agricultural University, Ludhiana, a site was picked in each zone that is more or less central and representative of the zone. In zone (iv) two sites were picked in view of its larger size relative to other zones. At each site, lists of farms were prepared, large enough so that randomly selected 10 percent of the farms would give the desired number of farms to be studied at each site. In the case of smaller villages, neighboring villages were included in the list. Table 3.1 gives the characteristics of this sample:

[1/] The agroclimatic zoning was done when Punjab and Haryana were one state and the three zones under consideration actually cover both the present States of Punjab and Haryana--extending from northwest to southeast. It is suggested that the sites selected for the Punjab investigation are reasonably representative of the counterpart zonal areas lying in Haryana State as well.

TABLE 3.1

DESCRIPTION OF THE REGIONALLY STRATIFIED SAMPLE, 1970/71

Zone	Name of District	Site	Villages Included	Number of Farms Studied
(ii)	Jullundur	I	Birak and Endhna Kalaske	46
(iii)	Sangrur	II	Shergarh-Cheema, Kasa-Pur and Abdula-Pur	31
(iv)	Bhatinda	III	Maur-Khurd	30
		IV	Jaid	21

The author was responsible for the design and supervision of data collection work for this sample. Whereas the data sheets or proformas and approach used were similar to 'Cost Accounting Method,' the farm visits were not as intensive. Each farmer was contacted periodically--not daily--to record his wheat-related activities. This sample will be referred to as 'RS Sample.'

A brief summary of the coverage and data used in this study is provided below in Table 3.2.

TABLE 3.2

BRIEF SUMMARY OF THE SAMPLES AND DATA

Sample	Geographic Coverage	No. of Villages Included	No. of Farms	Crop Year	Wheat Type	Observations Available
FZR	District-Ferozepur	15	150	1967/68	New	105
				1967/68	Old	132
				1968/69	New	144
TC	Punjab	19	304	1969/70	New	287
RS	Punjab	7	128	1970/71	New	128

The Region

The geographic area to which this investigation relates comprises the present state of Punjab. The state lies in the northwestern part of India between the latitudes 29° 30' and 32° 30' North and the longitudes 73° 53' and 77° East. The state is approximately 50,376 square kilometers in area which is 1.54 percent of the total area of India[1/] and is inhabited by 13.47 million people (Census of India, 1971). Estimated labor force is 3.88 million workers. Cultivators, agricultural laborers and other workers are 42.75 percent, 20.03 percent and 37.22 percent of the total workers in the state respectively.

Punjab agriculture is characterized by two distinct agricultural seasons. Maize, cotton, groundnuts, rice and sorghums are the important crops grown during summer, called the kharif season. Wheat

[1/]Economic Adviser to Government, Punjab (Jan. 1971; pp. 10,66, 69,122).

which is grown in winter or rabi season follows in rotation almost all kharif crops. Barley and gram are the other two rabi crops, but wheat occupies more than 85 percent of the area planted to rabi crops.[1/]

The state is mainly a flat alluvial plan with western Himalayan Mountains in the north. The soils are deep and fertile. The state has a well developed and diversified system of irrigation. The snowfed rivers entering the Punjab plains from the mountains have been well tapped for perennial irrigation through a well established canal system. The ground water is mostly suitable for irrigation and is easily reached. This has made tubewell irrigation quite popular. Diesel engines and electric motors ranging from 1 H.P. to about 25 H.P. capacity are common as power sources for lifting groundwater. During 1969/70, 74 percent of the total gross sown area was reported as irrigated.[2/]

The rainfall distribution over the year is heavily skewed during the monsoon months of July to middle of September with about 20"-24" of rainfall as compared to about 1"-3" during January, February, and March. The remaining months are almost completely dry. Temperatures range from freezing a few nights in January to about 110°-112° F in June.

The state has a well established rail and road transport system. Most villages are connected with some metalled (paved) road. Industrial units are generally small, agro-based and fairly well dispersed.

[1/] Ibid.

[2/] Ibid., page 41.

The Variables

The variables used in this study are defined as follows:

Y = physical output of wheat measured in quintals per farm including by-products.[1/] The by-products are converted into quintals of wheat by dividing the total value of by-products by wheat price.

N = the labor input per farm used for wheat production measured in hours. It includes both family and hired labor. Child and female labor is converted into man-equivalents by treating two children (or women) equal to one man.

L = the land input measured as acres of wheat grown per farm.

F = the current value of fertilizer and farm-produced manures measured in rupees per farm.

K = a measure of flow of capital services going into wheat production per farm. An hourly flow of services is derived for each durable input including capital in the form of livestock that the farm uses in wheat production. It includes depreciation charges, interest charges and operating expenses. Depreciation schedules are based on the specific life of each input, but interest costs are estimated at a uniform interest rate of 10 percent for annum.[2/] The actual number of hours

---

[1/] The major by-product is wheat straw, which in chaffed form is fed to cattle. Sometimes Sarson (an oilseed crop) is also grown mixed with wheat.

[2/] A.S. Kahlon, S.S. Miglani and S.K. Mehta (1968/69, p. 70) report that 68 percent of the amount borrowed in case of FZR Sample for the year 1968/69 was at an interest rate of 9-10 percent per annum. The range of interest charges varied from 6.5 to 20 percent.

of use times the hourly flow of services of each durable input gives its total service flow.[1/] Aggregation of these asset-specific service flows plus the seed costs yields a measure of the capital services.[2/]

B = a value measure of flow of services of animal power going into wheat production.

K_1 = the flow of total capital services less F and B, i.e., K_1 = K - F - B. It is the flow of capital services other than fertilizer and animal power.

K_2 = the flow of total capital services less F i.e., K_2 = K - F. It includes animal power but does not include fertilizer.

p = the price of wheat per quintal.

wN = the total wage bill in rupees for wheat production per farm. It includes payments to labor hired on daily wage basis, labor hired on annual contract basis and the imputed value of services of family labor. Family labor services are valued as equivalent to those of the annual contract labor for each farm. For farms which do not employ labor on annual contracts, the average rate of those farms in the sample which do employ contract labor was applied for evaluating the services of family labor.

[1/] For the RS Sample (1970/71), this procedure was carried out by the author himself. For FZR Sample and TC Sample, essentially the same procedure was employed.

[2/] Unless the estimating models have the value of fertilizer F as a separate variable K also includes F.

T = the total rental value of land services in rupees for wheat production per farm. It includes the actual rent paid for rented-in land in cash or share of the produce and the imputed rental value of owned lands. For imputing rental values of owned lands, the actual rental rates of the fields in close proximity considered as equivalent in land fertility are applied. For lands producing two crops during the year half of the annual rent is treated as the share of the wheat crop.

w = the hourly wage rate of labor. It is obtained simply by dividing the total wage bill wN by total labor input N.

t = the average rental price of land per acre per farm. It is obtained by dividing the total rental value of land per farm (T) by the wheat land per farm (L).

i = "price" of capital input.

E = the educational input calculated by dividing the sum of years of education of members of farm family older than 13 years of age by the number of these members. The members who do not directly participate in farm work are also included, assuming that their interaction influences the over-all decision making of farm households.

R = the total revenue from wheat production per farm in rupees. It is obtained by multiplying the total output of wheat Y by the reported price p.

C = the total cost of wheat produced per farm in rupees. It is the sum of wage bill wN, total land rent T, capital costs K.

P = the profit from wheat production is defined as total revenue less total variable labor costs.

CHAPTER IV

EMPIRICAL RESULTS AND THEIR INTERPRETATION: OLD VERSUS NEW WHEATS

The main objective in this chapter is to evaluate the nature and magnitude of change in technology of wheat production from old to new wheats. For this purpose the production function model (2.2), the cost function model (2.10) and profit function (Model I) are used employing 1967/68 data from the FZR Sample. Old wheat continued to be grown to some extent during the subsequent two years 1968/69 and 1969/70. But, since the number of farms growing this wheat and the area planted to it had been substantially reduced, no meaningful comparative analysis for these years is possible. Subsequent analyses for the new wheat, however, will be pursued using data for the four year period 1967/68 to 1970/71. In this chapter the main focus is to study the nature of technical change in wheat production as a result of the introduction of new wheats.

Production Function Model

The results from the least-squares regressions linear in natural logarithms for (2.2) are presented in Table 4.1. The output elasticities with respect to all inputs have the right signs and have reasonable values. There are three important conclusions that are obtained from these results. First we compare the separate regressions I and II with the pooled regression IV; and separate regressions V and VI with

TABLE 4.1

ESTIMATES OF PRODUCTION FUNCTION FOR WHEAT, 1967-68, PUNJAB, INDIA

Regression Number	Type of Wheat	Number of Observations	Constant	Coefficient of					R^2	SEE[a/]	Returns to Scale	F-ratio[b/]
				D^0	N	L	K or K_2	F				
I	Old	131	-0.254		0.098	0.500	0.429		0.835	0.352	1.027	0.42
			(0.585)		(0.082)	(0.086)	(0.093)					
II	New	105	-0.330		0.086	0.503	0.482		0.943	0.395	1.071	6.38**
			(0.680)		(0.093)	(0.092)	(0.128)					
III	Pooled	236	-0.906		0.089	0.406	0.552		0.914	0.381	1.048	4.60*
			(0.419)		(0.062)	(0.056)	(0.073)					
IV	Pooled	236	-0.195	-0.219	0.099	0.511	0.449		0.919	0.370	1.059	7.00**
			(0.446)	(0.056)	(0.060)	(0.061)	(0.076)					
V	Old	131	1.096		0.209	0.623	0.060	0.092	0.849	0.337	0.984	0.19
			(0.549)		(0.080)	(0.081)	(0.094)	(0.016)				
VI	New	105	0.175		0.091	0.528	0.328	0.116	0.943	0.395	1.062	4.75*
			(0.625)		(0.091)	(0.091)	(0.110)	(0.045)				
VII	Pooled	236	0.350		0.173	0.531	0.213	0.108	0.918	0.373	1.025	1.20
			(0.409)		(0.060)	(0.058)	(0.073)	(0.015)				
VIII	Pooled	236	0.698	-0.186	0.163	0.593	0.195	0.088	0.921	0.365	1.039	3.20
			(0.415)	(0.056)	(0.059)	(0.060)	(0.071)	(0.016)				

(Notes: see following page.

TABLE 4.1

(continued)

Notes:
Regressions linear in logarithms are estimated by least squares.

Dependent variable is output of wheat Y, in physical units.

D^0 is a dummy variable with a value of one for 'old wheat' and zero otherwise.

N, L, K or K_2 and F are labor, land, capital costs and fertilizer costs per farm. $K=K_2+F$. In regressions I to IV, K includes F.

Standard errors of coefficients are in parentheses.

*Significant at 95 percent level.

**Significant at 99 percent level.

a/ Standard errors of estimate are in natural logarithms of output of wheat measured in quintals.

b/ F-ratio is calculated to test the hypothesis of constant returns to scale.

R^2 is the coefficient of determination adjusted for degrees of freedom.

the pooled regression VIII, respectively. Analysis of covariance for these comparisons gave F-ratios[1/] of 0.27 with 3 and 228 degrees of freedom and 1.39 with 4 and 226 degrees of freedom; these are not significant at 90 percent level. Thus we cannot reject the hypothesis that output elasticities with respect to various inputs are the same in separate regressions for old and new wheats, if we allow the constant terms in the two regressions to differ.

Second, it can be observed from regressions VIII and IV that intercept terms for old wheat are lower by 18.60 percent and 21.90 percent respectively. Alternatively it means that the intercepts for new wheat are higher by 22.85 percent and 28.04 percent respectively as compared to old wheat. Economically this can be interpreted as a neutral upward shift in the wheat production function resulting from the introduction of new wheat.

The third important point to be noted is that when the model does not treat fertilizer as a separate input mildly increasing returns to scale are indicated for new wheat, in regressions II and III as well as the pooled regression IV. But for the pooled regressions VII and VIII constant returns to scale are indicated. It may also be noted that the last mentioned two regressions indicate substantial improvement relative to regressions III and IV, both in terms of the standard errors as well as the plausibility of the elasticity estimates. It seems that fertilizer as a separate input of production

---

[1/] See Johnston (1963, pp. 136, 137) and Chow (July, 1960) for an explanation of this test.

and an intercept-shifting dummy to capture the effects due to change in wheat type make slightly better specification for the production function model. The finding of a neutral upward shift of the order of 22.85 to 28.04 percent in the production function for wheat resulting from the introduction of new wheat is of great importance. The magnitude of the shift is almost unprecedented[1/] in the history of agricultural research effort. It has resulted in tremendous value to the society in terms of the savings of resources going into a unit of wheat and the consequent increased supplies of wheat made possible. Later in the chapter we evaluate the impact of this shift in terms of the resulting downward shift in the long run unit cost function for wheat.[2/]

The findings that the shift in the production function for wheat is of the neutral type and that constant returns to scale prevail in wheat production, facilitate considerably the quantification of the resulting shifts in the factor demand functions and the study of their consequences. We pursue this matter in the next section. In a later section we also compare the marginal value products of various inputs for old and new wheat. About the implications of the finding of constant returns to scale we will have more to say in later chapters.

[1/] Later from the profit function formulation, we find this shift to be still larger.

[2/] It would be possible to use these results to compute a rate of return to the applied research effort incurred in India on adapting the high-yielding varieties of wheat. But we have not been able to obtain the relevant data for this purpose on the expenditures incurred.

Input Demand Functions

The derived input demand functions are obtained by solving simultaneously the production function and the marginal productivity conditions. For the Cobb-Douglas case equations (2.5) to (2.7) are thus obtained as demand functions for N, L and K respectively. The demand function for fertilizer can be obtained in exactly the same way. It is important to note that for the case of constant returns to scale, since γ the measure of returns to scale is equal to one, these demand functions should be written without γ. This also permits us to evaluate these functions on a per acre basis by using the per acre sample mean levels of output Y for old and new wheats and compare their shifts.

For this purpose we run a least-squares regression restricting the estimates to constant returns to scale. These results are presented in (4.1):

$$(4.1)\quad \underset{}{\ln(Y/L)} = \underset{(.383)}{1.001} - \underset{(.055)}{.164D^0} + \underset{(.057)}{.139\ln(N/L)} + \underset{(.071)}{.173\ln(K/L)} + \underset{(.016)}{.088\ln(F/L)},^{1/}$$

$$SEE^{2/} = .367,\ R^2 = .370.$$

where D^0 is a dummy variable with a value of one for old wheat and zero for new wheat. A 17.30 percent neutral upward shift of the production

[1/]Figures in parentheses are the standard errors.

[2/]Standard error of estimate is measured in natural logarithms of per acre output of wheat measured in quintals.

function for new wheat is indicated relative to the old wheat.

From (4.1) the production function estimates for new and old wheats can be written as (4.2) and (4.3) respectively:[3/]

$$(4.2) \qquad Y = 2.718\ N^{.139}\ L^{.600}\ K_2^{.173}\ F^{.088} \qquad \text{(new wheat)}$$

$$(4.3) \qquad Y = 2.316\ N^{.139}\ L^{.600}\ K_2^{.173}\ F^{.088} \qquad \text{(old wheat)}$$

Equatinns (4.2) and (4.3) are the estimates for old and new wheat obtained with the restriction of constant returns to scale in (all) the inputs of labor, land, capital (K_2) and fertilizer.

It should be noted that the input elasticities with the restriction of constant returns to scale in (4.2) and (4.3) differ slightly from the unrestricted estimates of regression VIII in Table 4.1. By substituting the production coefficients from (4.2) in demand functions (2.5) to (2.7) and a similar function for fertilizer, the input demand functions for N, L, K and F by farms producing new wheat for the constant returns to scale case are given by:

$$(4.4) \qquad N = .152\ Y\ w^{-.861}\ t^{.600}\ i^{.173}\ p_f^{.088}$$

$$L = .656\ Y\ w^{.139}\ t^{-.400}\ i^{.173}\ p_f^{.088}$$

[3/] The coefficient for land L is derived implicitly from estimates of (4.1). Per acre production function with four inputs can be written:

$$\frac{Y}{L} = A \left(\frac{N}{L}\right)^{\alpha_1} \left(\frac{K_2}{L}\right)^{\alpha_3} \left(\frac{F}{L}\right)^{\alpha_4} \quad . \text{ Thus}$$

$$Y = A\ N^{\alpha_1}\ L^{(1-\alpha_1-\alpha_3-\alpha_4)}\ K_2^{\alpha_3}\ F^{\alpha_4} \quad \text{that is, coefficient for land}$$

$\alpha_2 = (1-\alpha_1-\alpha_3-\alpha_4)$.

$$K = .189\ Y\ w^{.139}\ t^{.600}\ i^{-.827}\ p_f^{.088}$$

$$F = .096\ Y\ w^{.139}\ t^{.600}\ i^{.173}\ p_f^{-.912}$$

By a similar substitution of the production coefficients from (4.3) in demand functions (2.5) to (2.7) and a similar function for fertilizer, demand functions for N, L, K and F by farms producing old wheat are given by

(4.5) $$N = .178\ Y\ w^{-.861}\ t^{.600}\ i^{.173}\ p_f^{.088}$$

$$L = .770\ Y\ w^{.139}\ t^{-.400}\ i^{.173}\ p_f^{.088}$$

$$K = .220\ Y\ w^{.139}\ t^{.600}\ i^{-.827}\ p_f^{.088}$$

$$F = .112\ Y\ w^{.139}\ t^{.600}\ i^{.173}\ p_f^{-.912}$$

If we divide both sides of the demand functions for N, K and F in (4.4) and (4.5) by L, we get per acre demand functions. By substituting the sample mean per acre output of the respective wheat in the righthand side and multiplying it by the respective sample mean price[1/] we find that these per acre demand functions for new wheat are higher by 25 percent compared to the old wheat. This shift in the factor demand functions in wheat industry has important implications

---

[1/] These sample means for the year 1967/68 are:

	New Wheat	Old Wheat
Output per acre (quintals):	13.00	8.50
Price per quintal (Rupees):	76.37	79.86

for factor markets and the labor absorbtive capacity of 'green revolution'. By way of illustration we work out one example to throw some light on this point. The wheat area replaced by new wheat in Punjab was 3.6 percent, 35.4 percent, 48.5 percent and 65.5 percent during the years 1966/67, 1967/68, 1968/69 and 1969/70 respectively.[1/] If we assume perfectly elastic labor supply, a 25 percent rightward shift in the labor demand function implies that labor absorption in wheat production in Punjab during these years increased by 0.9 percent (1966/67), 8.85 percent (1967/68), 12.13 percent (1968/69) and 16.38 percent (1969/70). Similar repercussions in other factor markets could obviously be expected.

Cost Function Model

In this section we provide a quantitative assessment of the nature and magnitude of shift in the long-run cost function of wheat resulting from the introduction of high yielding wheats. Since the cost function and the underlying Cobb-Douglas production function are related to each other by the duality theorem, from the estimated cost function we also obtain the input elasticities. Also we examine the question of returns to scale. Least squares regression results separately for old and new wheats and for the pooled data for equation (2.10) are given in Table 4.2; the indirectly derived parameters of the production function are given in Table 4.3.

[1/] See Appendix Table I.2.

TABLE 4.2

ESTIMATES OF COST FUNCTION FOR WHEAT BASED ON EQUATION 2.10, 1967/68, PUNJAB, INDIA

Regression Number	Type of Wheat	Number of Observations	Constant	Coefficient of D^0	Coefficient of Y	Coefficient of w	Coefficient of t	R^2	SEE[a/]	Returns to Scale
I	Old	131	3.871 (0.361)		0.821 (0.031)	0.059 (0.090)	0.155 (0.057)	0.845	0.307	1.128*
II	New	105	3.907 (0.516)		0.868 (0.023)	0.118 (0.119)	0.089 (0.085)	0.943	0.358	1.152*
III	Pooled	236	3.764 (0.306)		0.872 (0.018)	0.077 (0.075)	0.126 (0.050)	0.918	0.342	1.146*
IV	Pooled	236	3.695 (0.296)	0.184 (0.044)	0.857 (0.017)	0.089 (0.072)	0.130 (0.048)	0.923	0.330	1.166*

Notes:
Regressions linear in logarithms are estimated by least squares. Dependent variable is total cost C of wheat in rupees per farm, D^0 is a dummy variable with a value of one for 'old wheat' and zero otherwise. Y, w and t are the output of wheat per farm in physical units, wage rate per hour and the rent of wheat land per acre respectively. The standard errors of coefficients are in parentheses.
a/ Standard errors of estimate are in natural logarithms of total cost of producing wheat per farm in rupees.
*Indicates that returns to scale are different from one at 95 percent level of significance.

TABLE 4.3

INPUT ELASTICITIES AND RETURNS TO SCALE DERIVED FROM ESTIMATES OF THE COST FUNCTION PRESENTED IN TABLE 4.2

Regression Number	Input Elasticities of			Returns to Scale
	Labor	Land	Capital (K)	
I	0.072	0.189	0.957	1.128*
II	0.136	0.103	0.913	1.152*
III	0.088	0.144	0.914	1.146*
IV	0.105	0.152	0.909	1.166*

*Indicates that returns to scale are different from one at 99 percent level of significance.

Estimates in Table 4.2 indicate that constant terms of old and new wheats differ by 18.40 percent. An analysis of covariance test comparing the separate regressions for old and new wheats (I and II) with the over-all regression IV yields an F-ratio of 0.79 with 3 and 228 degrees of freedom. This means that the two cost functions differ only in the intercept and not in slopes. This is quite a valuable result. It implies that with the introduction of high-yielding wheats the long-run unit cost function has neutrally shifted downward on the order of 15.54 percent.

The estimated coefficient $\left(\frac{\hat{\delta}}{\gamma}\right)$ for the dummy variable D^0 is 0.184 for regression IV and the estimate for γ is 1.166. Thus $\hat{\delta}$ = 21.45 percent, which is the neutral upward shift in the production function.

Both for the separate and pooled regressions increasing returns to scale are indicated. But $\widehat{\left(\frac{1}{\gamma}\right)}$, the coefficient for logarithm of Y, could be biased downward since the model does not include the 'capital price' as an explanatory variable, which on a priori considerations[1/] may be negatively correlated with output. Thus returns to scale may be over-estimated.

The second difficulty with these estimates is indicated by implausibly low values of output elasticities with respect to land (Table 4.3) and vice versa for capital. Again the omitted variable effect is probably the reason. The per acre land rent t and output per farm Y are positively correlated[2/] and this implies a negative correlation between t and the omitted variable 'capital price.' The estimated coefficients for logarithm of t in Table 4.2 and the derived output elasticities with respect to land (Table 4.3) are thus biased downward.

Profit Function Model

In this section we have two purposes in hand: to reassess the magnitude of the neutral upward shift in the wheat production function and to obtain consistent estimates of the output elasticities with respect to the different inputs.

First we reproduce equations (2.47) and (2.32)--Model I-- as (4.6) and (4.7) with minor changes:[3/]

[1/] See discussion on this point in Chapter I, p. 6.

[2/] The simple correlation coefficient is 0.395.

[3/] Equation (4.6) is written after introducing a dummy variable D^N with a value of one for new wheat and zero otherwise in equation (2.47).

(4.6) $\ln \pi = \lambda + \delta^N D^N + \beta_1 \ln w + \beta_2 \ln L + \beta_3 \ln K$

where

$$\lambda = \ln A_*^0 + (1-\beta_1) \ln p$$

D^N is a dummy variable with value of one for new wheat and zero for the old wheat.

δ^N if significantly different from zero and positive indicates the percent upward shift in the profit function.

A_*^0 is defined by the identity in (2.34) and the remaining variables and parameters are as defined earlier. Superscript 0 stands for old wheat.

(4.7) $-\frac{w \cdot N}{\pi} = \beta_1$

Equations (4.6) and (4.7) are estimated jointly using Zellner's method[1/] of estimation by imposing the restrictions that $\beta_1 = \beta_1$ in the two equations and requiring that $\beta_2 + \beta_3 = 1$, that is, assuming constant returns to scale. These results are presented below in Table 4.4:

Also notice that (2.32) holds without output price and can be written as (4.7).

[1/] See Zellner (1962) and subsequent applications by Lau and Yotopoulos (March 1971, February 1972).

TABLE 4.4

RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR WHEAT, 1967/68, PUNJAB, INDIA

Parameter		Estimated Coefficient	Standard Error
λ	=	4.872	(0.965)
δ^N	=	0.485	(0.129)
β_1	=	0.254	(0.013) in both equations
β_2	=	0.670	(0.155)
β_3	=	0.330	(0.155)

From $\lambda = \ln A_*^0 + (1-\beta_1) \ln p$ we evaluate A_*^0 by substituting sample's mean value of $\ln p$ for old wheat. Then we get A^0 the efficiency parameter in the cobb-Douglas production function for old wheat from the identity in (2.34), the computed value of which is 5.641. In the same way, from $\lambda = \ln A_*^0 + \delta^N + (1-\beta_1) \ln p$, we get A^N the efficiency parameter for new wheat = 8.166. Thus maintaining the hypothesis of neutral technical shift we find that the efficiency parameter for the new wheat production function is larger by 44.70 percent. It should be noted that this increase in efficiency parameter of wheat production function, as a result of the introduction of new wheats, is much larger, relative to the direct production function estimates of 22.85 percent to 28.04 presented earlier (p. 51).

This larger efficiency gain is quite consistent with the percentage increase of output per acre resulting from the introduction of new wheats, which, calculated at the respective geometric mean levels for old and new wheats, is of the order of 47.93 percent. It may well be the result of superior estimation properties of the profit function model.

The indirect estimates for the output elasticities with respect to inputs of labor, land and capital are obtained from the identities in (2.30) or (2.34). In Table 4.5 these estimates are compared with those derived from the cost function estimates and direct production function estimates of regression IV, Table 4.1.

TABLE 4.5

ESTIMATES OF OUTPUT ELASTICITIES FOR WHEAT PRODUCTION FUNCTION 1967/68, PUNJAB, INDIA

Parameter		Indirect Estimates Derived From Profit Function	Indirect Estimates Derived From Cost Function	Direct Production Function Estimate
Labor	α_1	0.202	0.105	0.099
Land	α_2	0.535	0.152	0.511
Capital	α_3	0.263	0.909	0.449

To the extent simultaneous equation bias exists the direct production estimates may not be free from it. Also as argued before, indirectly derived elasticity estimates from the cost function suffer from the bias created by the excluded variable effect. On the other hand, indirectly derived from the Cobb-Douglas profit function, estimates are statistically consistent and also look quite reasonable. In Table 4.6 we use these output elasticities along with those from direct production function estimates (regressions VIII and IV, Table 4.1) to calculate marginal value products for various inputs in the production of old and new wheats and compare them with their opportunity prices.

Two broad comments seem to follow from the information presented in Table 4.6. First, the calculated marginal value product of land is considerably larger for new wheat compared to the old wheat and in either case much above the sample's geometric mean value of land rent per acre. This increase in land productivity resulting from the introduction of high-yielding varieties of wheat was in subsequent years reflected in rising land values and land rents. In view of the relatively inelastic supply of land, large windfall gains (economic rent) accrued to the owners of farm land.[1] Second, a seemingly unreasonable

---

[1] See Robert W. Herdt and Willard W. Cochrane (1966) for a perspective on capitalization of the gains of technological advance in the form of increased land values.

TABLE 4.6

AVERAGE AND MARGINAL VALUE PRODUCTS FOR DIFFERENT INPUTS IN THE PRODUCTION OF OLD AND NEW WHEAT, 1967/68, PUNJAB, INDIA
(Calculated at geometric means)

Input	Geometric Means		Average Value Products		Marginal Value Products Using Output Elasticities From: Regression VIII (Table 4.1)		Regression IV (Table 4.1)		Derived From Profit Function (Table 4.4)		Geometric Mean Price From the Sample
	Old Wheat	New Wheat	Old Wheat	New Wheat	Old Wheat	New Wheat	Old Wheat	New Wheat	Old Wheat	New Wheat	
			----------rupees per unit of input----------								
Labor (hrs)	1064.30	590.11	4.09	4.21	0.65	0.67	0.41	0.42	0.82	0.84	0.69[a/]
Land (acres)	6.62	2.67	658.66	931.59	388.61	549.60	335.92	475.11	355.68	503.06	139.15[b/]
Capital, K (Rs)	1313.40	820.72	3.31	3.03			1.49	1.36	0.86	0.79	
Capital, K_2 (Rs)	1107.60	590.50	3.93	4.21	0.79	0.84					
Fertilizer (Rs)	100.48	184.93	43.39	13.45	3.91	1.18					
Output (quintals)	54.60	32.57									
Output price* (Rs/quintal)	79.86	76.37									

a/ Samples geometric mean wage rate per hour.
b/ Samples geometric mean land rent per acre.
*Sample arithmatic means.
(For definition of variables see Chapter III.

magnitude for the value of marginal product of fertilizer in the production of old wheat--about three and a half times larger than in the case of new wheat--provides an interesting verification for the hypothesis of 'yield ceiling' in the case of old wheats.[1/] The main point of this hypothesis is that old Indian varieties of wheat which have tall-growing tender straw are susceptible to lodging under heavy fertilization and that this characteristic works as a limiting factor for increasing their yields beyond a certain upper limit called the 'yield ceiling.' The observed high value for the marginal product of fertilizer in the production of old wheat is thus explained by the existence of a discontinuity in the marginal product curve for fertilizer. It should have no connotation for a possible irrationality on the part of producers in the use of fertilizer or for the possibility of increasing output of old wheat by increased fertilization.

Summary

The results shown above indicate that the high-yielding varieties of wheat have shifted the wheat production function upward in a neutral way. The direct production function estimates IV and VIII, Table 4.1, indicate the magnitude of this shift as 22.85 percent and 28.04 percent respectively. The cost function estimates show this shift as 21.45 percent whereas the profit function estimate is a 44.70 percent shift.

[1/] See Appendix I, p. 186, for further discussion of this point.

From the cost function estimates we also find that the long-run average cost function for wheat shifted downward by 15.54 percent.

The calculated marginal value products for labor, land and fertilizer at the geometric means are significantly above their opportunity prices. The difference is quite large in case of land and fertilizer.

CHAPTER V

EMPIRICAL RESULTS AND THEIR INTERPRETATION: PRODUCTION AND COST RELATIONSHIPS FOR THE NEW WHEAT AND ROLE OF EDUCATION IN PRODUCTION, 1967/68-1970/71

In this chapter we attempt to analyze the nature of change in the new wheat production function and in the long-run cost function over the four year period 1967/68-1970/71, to study the role of education and animal power as factors of production, to provide the best possible estimates of the production function and to obtain some useful elasticity measures. The basic tools for these analyses are (1) the production function, (Model 2.2), (2) the cost function, (Model 2.10), and (3) the profit function (Model I: Equations 2.47 and 2.32).

Production Function Model

The results of the least-squares estimates as suggested by Model 2.2 are summarized in Tables 5.1 and 5.2. Regressions in Table 5.1 treat fertilizer as a separate factor of production in the specification of the production function, but in Table 5.2 fertilizer is included in the capital variable K, the flow measure of total capital. At a 95 percent level of significance mildly increasing returns to scale are indicated for the years 1967/68 and 1970/71. For these years there is a relatively large number of observations with output level below the respective sample means, and these probably account for the mildly increasing returns. By and large, however, constant returns seem to prevail.

In order to test the hypothesis of the equality between sets of production coefficients in the production functions for the years

1967/68, 1968/69, 1969/70, 1970/71, we compare the separate regressions I, II, III and IV with over-all regression V in Tables 5.1 and 5.2. The respective F-ratios are 5.30 with 15 and 636 degrees of freedom and 6.17 with 12 and 640 degrees of freedom. These F-ratios are significant at 99 percent level. Thus, the hypothesis of equality between the sets of coefficients in the four yearly regressions is rejected, indicating that the production function for the new wheat over the four year period has been unstable. It is, however, necessary to go a step further. In over-all regressions VI we note that each of the coefficients for the three 'year dummy variables' has a negative sign and is significant at 99 percent level, and the analysis of covariance comparing the separate yearly regressions with over-all regressions VI (Tables 5.1 and 5.2) gave F-ratios of 2.27 with 12 and 636 degrees of freedom and 2.05 with 9 and 640 degrees of freedom. Both these F-ratios are significant at 95 percent level (but not 99 percent). That is, the hypothesis of equality between the sets of slope coefficients allowing the intercepts in the yearly regressions to vary, is rejected less strongly. Thus, while we reject on statistical grounds the hypothesis of neutral variations in favor of non-neutral variations in the production function over the four year period, the evidence is rather weak. Unusually small standard errors for the coefficients of the 'year dummy variables' support the view that exogenous factors like weather and deterioration[1/] in quality of seed may account for the downward

---

[1/] During my farm visits in 1970 and 1971, farmers in Punjab generally complained of defective seed quality after 1967/68, that is, that seed did not perform as well during later years. I think mixing of some lower quality seed with better seeds occurred at various levels of seed distribution channel. During 1968/69, 1969/70 and 1970/71 crop years weather as well was somewhat adverse relative to 1967/68.

TABLE 5.1

ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA

Year	1967/68	1968/69	1969/70	1970/71	Over-all		
Regression Number	I	II	III	IV	V	VI	VII[a]
No. of Observations	105	136	287	128	656	656	656
Constant	0.175	0.678	1.064	-1.733	0.333	0.304	-2.549
	(0.625)	(0.898)	(0.305)	(0.564)	(0.230)	(0.253)	(0.092)
D_1						-0.298	-0.477
						(0.047)	(0.049)
D_2						-0.282	-0.462
						(0.044)	(0.046)
D_3						-0.171	-0.411
						(0.048)	(0.049)
Labor	0.091	0.198	0.113	0.473	0.209	0.190	0.194
	(0.091)	(0.146)	(.052)	(0.094)	(0.040)	(0.040)	(0.032)
Land	0.528	0.577	0.723	0.305	0.604	0.613	0.500
	(0.091)	(0.135)	(0.062)	(0.099)	(0.039)	(0.043)	(0.032)
Capital, K_2	0.328	0.108	0.127	0.173	0.099	0.161	0.244
	(0.110)	(0.127)	(0.051)	(0.072)	(0.015)	(0.039)	(0.035)
Fertilizer	0.116	0.110	0.031	0.110	0.082	0.066	0.068
	(0.044)	(0.033)	(0.018)	(0.032)	(0.016)	(0.014)	(0.014)
R^2	0.943	0.875	0.877	0.922	0.908	0.915	0.916
SEE[b]	0.395	0.405	0.324	0.255	0.359	0.347	0.343
Returns to scale	1.062	0.993	0.993	1.061	0.994	1.030	1.006
F-ratio[c]	4.75*	0.04	0.09	4.51*	0.23	2.50	0.15

Notes: Equations linear in logarithms are estimated by least squares.

Dependent variable is output of wheat in physical units.

D_i (i = 1,2,3) are the year dummies taking the value of one for 1968/69, 1969/70 and 1970/71 respectively and zero otherwise.

Standard errors of coefficients are in parentheses.

[a] The inputs for this regression are measured in value terms.

[b] Standard errors of estimate are in natural logarithms of wheat output measured in quintals.

[c] The calculated F-ratio is for testing the hypothesis of constant returns to scale.

*Indicates the F-ratio is significant at 95 percent level.

R^2 is the coefficient of determination adjusted for degrees of freedom.

TABLE 5.2

ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA

Year	1967/68	1968/69	1969/70	1970/71	Over-all		
Regression Number	I	II	II	IV	V	VI	VII[a]
No. of Observations	105	136	287	128	656	656	656
Constant	-0.330	-0.116	0.757	-2.157	-0.310	-0.073	-2.804
	(0.680)	(0.923)	(0.330)	(0.574)	(0.272)	(0.266)	(0.096)
D_1						-0.308	-0.473
						(0.047)	(0.048)
D_2						-0.287	-0.454
						(0.043)	(0.046)
D_3						-0.169	-0.396
						(0.048)	(0.049)
Labor	0.086	0.172	0.096	0.418	0.156	0.163	0.181
	(0.093)	(0.148)	(0.056)	(0.094)	(0.042)	(0.041)	(0.032)
Land	0.503	0.522	0.692	0.282	0.531	0.582	0.475
	(0.092)	(0.139)	(0.063)	(0.098)	(0.044)	(0.043)	(0.033)
Capital, K	0.482	0.325	0.206	0.369	0.313	0.291	0.357
	(0.128)	(0.133)	(0.054)	(0.083)	(0.044)	(0.042)	(0.038)
R^2	0.943	0.871	0.879	0.924	0.909	0.915	0.917
SEE[b]	0.395	0.411	0.321	0.252	0.359	0.345	0.342
Returns to scale	1.071	1.019	0.994	1.069	1.000	1.036	1.013
F-ratio	6.37*	0.31	0.06	6.24*	0.01	6.00*	0.85

Notes: Equations linear in logarithms are estimated by least squares.

Dependent variable is output of wheat in physical units.

D_i (i = 1,2,3) are the year dummies with a value of one for 1968/69, 1969/70 and 1970/71 respectively and zero otherwise.

Standard errors of coefficients are in parentheses.

[a] The inputs for this regression are measured in value terms.

[b] Standard errors of estimate are in natural logarithms of wheat output measured in quintals.

[c] The calculated F-ratio is for testing the hypothesis of constant returns to scale.

*Indicates the F-ratio is significant at 95 percent level.

R^2 is the coefficient of determination adjusted for degrees of freedom.

shift[1] in the new wheat production function in the years subsequent to 1967/68. Another explanation could be that during the year 1967/68 the new wheats were planted on the best available wheat lands and marginally inferior lands were added during the next two years. It seems reasonable that all the three factors, adverse weather, deterioration of seed and addition of marginally inferior lands in production, may have contributed to a downward shift in the production function after 1967/68, but an assessment of their relative influences seems impossible.

By inference the results raise an important question. We observe that the absolute size of the coefficient for the year 1970/71 is much smaller than the coefficients for 1968/69 and 1969/70, which means that the downward drift was to some extent reversed. The question is whether the downward drift is a temporary phenomenon or a long-run technological regression in the production of new wheats. The problem seems to be worth investigation by the wheat breeders and agronomists. Later in this chapter the magnitudes of these shifts are measured somewhat more precisely from the profit function model.

The introduction of year dummies into the model in regression VI improved slightly the estimates of the input elasticities both in terms

---

[1] Because the observed shifts are downward, we seem to be involved in a terminological problem. Normally, the production function shifts due to neutral or non-neutral technical change would be expected to be upward rather than downward. Our usage of the word shift, however, is intended to relate only to the stability of the new wheat production relationship during the four year period studied.

of the fit of the equations as well as the standard errors. These estimates seem to be quite reasonable and will be compared later with indirectly derived estimates. For regression VII all inputs are measured in value terms. This resulted in lower standard errors of all the coefficients and slightly better fit for the equations. One possible explanation for this result could be that part of the quality adjustments for the inputs (in particular land) is taken care by the value measure. Separate yearly regressions using inputs in value terms are presented in Appendix Tables IV.1 and IV.2. Comparison of these regressions with the over-all regressions VII, however, does not change our conclusion regarding the nature of yearly shifts in the production function.

As was pointed out earlier, statistical evidence points out (although not very strongly) that, in the new wheat production function, apart from the efficiency parameter, there have been some yearly changes in the output elasticities as well. We have also observed that during the four years studied weather, seed quality and land quality may have been changing to some degree. It seems possible to argue that the 'year dummy variables' only partially captured the effects of these factors and that their remaining influence caused yearly changes in the behavior of output elasticities. It is not difficult to imagine that weather differences could cause differential increase in the rate of application of various inputs. Bringing marginally inferior land into new wheat production after 1967/68, also meant a non-constant input of land services during the four years. The observed yearly differences in the behavior of output elasticities thus seem to be a reasonable or expected phenomenon. This, however, is not the same thing as saying that there would have been non-neutral differences in the true new wheat production function in homogeneous inputs during the four years studied. In fact, subsequent evidence from the cost function model, which employs exogenous independent variables, shows clearly that the yearly changes in the new wheat production function are of the neutral type. In subsequent analysis, therefore, we maintain that the yearly differences in the new wheat production function were neutral in character, that is, the efficiency parameter in the production function changed but not the output elasticities. This enables us to pool the four years' data for various estimation purposes.

There is an additional reason for maintaining this hypothesis. In agriculture weather is an important factor responsible for causing considerable variability in annual production. Application of least squares to individual farm observations for estimating the parameters of a Cobb-Douglas production function is an averaging process. It seems that the estimates obtained from this averaging process, using four years' data, should have better predictive value than those obtained from a single cross-section. For this reason production function estimates obtained from the four years' pooled data, particularly those employing value measure of inputs--regression VII in Tables 5.1 and 5.2--are considered relatively better estimates. The consequences of the year to year differences in the production function on cost function are traced in a later section where we use the cost function model.

Education and Animal Power as Factors of Production

So far we have not treated education and animal power as separate variables to distinguish their role as factors of production. Animal power has been included (as a component) in the flow of capital services and education has been ignored. Efforts to include animal power as a separate variable in the production function estimates for the pooled data were not successful in the sense that a nonsignificant coefficient with a negative sign was obtained. A possible reason for this is that in the tractor cultivation sample (applying to 1969/70), a large number[1/] of tractor-operated farms (observations) had relatively little input of animal power, making the simple correlation coefficient between the dependent variable and animal power negative. This in turn resulted in a weak correlation between the dependent variable and animal power for the four years' pooled data with the result that high intercorrelation between the other independent variables caused the partial correlation coefficient between them to be negative. Hence we obtained a negative coefficient for animal power. The results are somewhat improved if we exclude observations for the years 1969/70 from our set of pooled data.

For this reason (and also because we do not have data on the education variable for 1969/70), in this section we work only with the

---

[1/] One hundred and five.

remaining three years' data in trying to assess the roles of education and animal power in production. The approach used is stranghtforward. We introduce education and animal power as additional (separate) variables in the production function (Model 2.2).

Before going any further it may be useful to point out the inadequacy of our production model for studying the productive value of education. We are dealing with a single crop out of a rather diversified set of enterprises on Punjab farms. In essence, we are abstracting from the great complexity of farmers' decision-making routines. We would expect that education would enhance the allocative ability of the farm household more than it would enhance their capability to perform various agricultural tasks.[1/] But because we are estimating the results from only one crop, the effects of allocative abilities do not affect the results very much. Our function thus enables us to capture only one kind of education effect (worker effect),[2/] as a direct contribution of education to physical output. The estimated production elasticity for education obtained from our production model, will be an underestimate of the true productive value of education. We will say more about this point later.

Yotopoulos (1968), Chaudhri (1969), Hayami (1969), Welch (1970) and Herdt (1971) are some of the recent studies which have explicity viewed education as a factor of production in production function

---

1/ See F. Welch (1970) for these ideas.

2/ *Ibid.*, page 71.

analysis. Hayami's study (1969) demonstrates differences in education as an important source of differences in agricultural productivity among nations. Yotopoulos (1968) shows that a small amount of education (2.24 years per household) is an important factor of production in Greek agriculture. Chaudhri (1969) estimates a district-level aggregate production function of gross revenue and treats education as one of the influencing variables. His results seem to support the view that the level of agricultural productivity in Indian agriculture is significantly related to the level of education even though the estimated coefficient (0.08) is small compared to 0.41 from Hayami's study and 0.14 from the study by Yotopoulos. Herdt (1971) estimated an aggregate production function (at the state level) for Indian agriculture for 1965, but obtained negative or nonsignificant coefficients for education. In part his problem seems to be statistical--few observations and high intercorrelations--and in one case an incorrect selection of the measure representing education.[1/] As an explanation of his results (and considering the relatively small coefficient for education from Chaudhri's study), Herdt argues that lack of technological complexity in Indian agriculture and uniform nature of this technology across the country result in little direct effect of education on agricultural production. The implication, of course, is that, in view of the stationary nature of technology, the

---

[1/] He uses the number of village level workers per state to represent agricultural extension education. But the number of village level workers per unit of population is uniform in all states of India. This makes the variables 'education' and 'labor' linearly dependent upon each other.

extensive observations farmers make of other farmers (education or no education) result in efficient judgments about selection of factors and their use. In what follows we consider education and animal power as any other factors of production and try to assess their contribution to the physical output of wheat.

In Table 5.3, we present production function estimates of the unrestricted Cobb-Douglas form (Model 2.2) for the year 1967/68 using the usual variables of labor, land, capital (K_2) and fertilizer, and introduce education in addition. It is interesting to observe that the introduction of education has almost no effect on other coefficients estimated without education. The coefficient for education is significant at 95 percent level using one-tailed t tests, and remains unchanged in regressions treating fertilizer as a separate variable and when it is combined with other capital.

Table 5.4 provides similar estimates for the new wheat by pooling observations over the years 1967/68, 1968/69 and 1970/71, with animal power as a separate variable. Here again addition of education has relatively little effect on other coefficients estimated without education. Also different specifications of the capital input, i.e., treating animal power and fertilizer as separate inputs or combining them into capital, has very little effect on the estimated value of the coefficient for education. Though relatively small, the coefficient itself is significant at 97.5 percent level.

It would be helpful at this point to repeat the earlier argument that our single crop function would yield an underestimate of the true

TABLE 5.3

PRODUCTION FUNCTION FOR WHEAT 1967/68, PUNJAB, INDIA, INCLUDING EDUCATION AS A SEPARATE VARIABLE

Number of Observations = 236

Regression Number	I	II	III	IV
Constant	0.639	0.698	-0.221	-0.195
	(0.414)	(0.415)	(0.441)	(0.446)
D^o	-0.185	-0.186	-0.218	-0.219
	(0.056)	(0.056)	(0.055)	(0.056)
Labor	0.163	0.163	0.102	0.099
	(0.058)	(0.059)	(0.060)	(0.060)
Land	0.590	0.593	0.512	0.511
	(0.060)	(0.060)	(0.061)	(0.061)
Capital (K or K_2)	0.199	0.195	0.444	0.449
	(0.071)	(0.071)	(0.075)	(0.076)
Fertilizer	0.087	0.088		
	(0.016)	(0.016)		
Education	0.038*		0.037*	
	(0.020)		(0.020)	
$\bar{R}^2$	0.922	0.921	0.920	0.919
SEE[a]	0.363	0.365	0.368	0.370

Notes: Regressions linear in logarithms are estimated by least squares.

Dependent variable is output of wheat , in physical units.
K (the total capital) applies to regressions III and IV.
D^o is a dummy variable with a value of one for 'old wheat,' and zero for the 'new wheat.'
K_2 (K - fertilizer) applies to regressions I and II.
Education is the index of education per farm household. It is obtained by dividing the sum of years of schooling of adult members (older than 13 years) by their number.

Standard errors of coefficients are in parenthesis.

*Significant at 95 percent level using one-tailed t test.

a/ Standard errors of estimate are in natural logarithms of wheat output measured in quintals.

$\bar{R}^2$ is the coefficient of determination adjusted for degrees of freedom.

TABLE 5.4

PRODUCTION FUNCTION FOR NEW WHEAT 1967/68, 1968/69, AND 1970/71, PUNJAB, INDIA, INCLUDING EDUCATION AS A SEPARATE VARIABLE

Number of Observations = 369

Regression Number	I	II	III	IV	V	VI	Sample Means (Geometric)	AVP[b] Regression I	MVP[b] Regression I
Constant	0.005	0.045	-0.209	-0.174	-0.692	-0.684			
	(0.325)	(0.326)	(0.344)	(0.345)	(0.360)	(0.361)			
D_1	-0.292	-0.291	-0.299	-0.298	-0.320	-0.319			
	(0.051)	(0.051)	(0.050)	(0.050)	(0.049)	(0.050)			
D_2	0.142	-0.166	0.162	-0.186	-0.165	-0.188			
	(0.053)	(0.052)	(0.052)	(0.051)	(0.052)	(0.051)			
Labor	0.245	0.237	0.207	0.199	0.189	0.179	1326.30	3.56	0.87
	(0.058)	(0.058)	(0.060)	(0.060)	(0.061)	(0.061)			
Land	0.549	0.548	0.536	0.535	0.500	0.497	5.81	796.94	437.52
	(0.059)	(0.059)	(0.059)	(0.059)	(0.059)	(0.059)			
Capital (K_1,K_2,or K)	0.132	0.138	0.203	0.210	0.364	0.379	713.58	6.43	0.85
	(0.045)	(0.045)	(0.059)	(0.060)	(0.067)	(0.066)			
Animal Power	0.014	0.015					357.00	12.81	0.18
	(0.014)	(0.014)							
Fertilizer	0.094	0.097	0.097	0.100			340.00	13.48	1.27
	(0.021)	(0.021)	(0.021)	(0.021)					
Education	0.036*		0.035*		0.033*		2.49	1846.04	66.46
	(0.016)		(0.016)		(0.016)				
R^2	0.924	0.923	0.925	0.924	0.925	0.924			
SEE[a]	0.359	0.361	0.357	0.359	0.358	0.360			

Notes on following page.

TABLE 5.4 (continued)

Notes: Regressions linear in logarithms are estimated by least squares.

Dependent variable is output of wheat in physical units.

D_i are the dummy variables with a value of one for the years 1968/69 and 1970/71 respectively and zero elsewhere.
K the (total capital) applies to regressions V and VI. K_2 (K-fertilizer) applies to regressions III and IV. $K_1 = (K - F - B)$ applies to regressions I and II.
Animal power is measured in value terms as flow of bullock services used for wheat production.

Education is the index of education per farm household. It is obtained by dividing the sum of years of schooling of adult members (older than 13 years) by their number.

Standard errors of coefficients are in parentheses.

* Significant at 97.5 percent level using one-tailed t test.

[a/] Standard errors of estimate are in natural logarithms of wheat output measured in quintals.

[b/] Average value products (AVP) and marginal value products (MVP) are in rupees per unit of the respective inputs.

R^2 is the coefficient of determination adjusted for degrees of freedom.

coefficient for education. It also may be useful to summarize some of the ideas from Welch (1970), who distinguishes two distinct kinds of effects which constitute the productive value of education. The first, what he calls 'worker effect,' is the result of better job performance which may result from increased education. This may simply permit a worker to accomplish more from given resources. The second kind of effect--which Welch holds is more important in agriculture--is associated with enhancement of a worker's allocative ability with increases in his education; he can make better decisions regarding selection of inputs and their efficient distribution between competing uses. He calls this 'allocative effect' and argues:[1/] "Agriculture is probably atypical inasmuch as a larger share of the productive value of education may refer to allocative ability than in most industries." He also demonstrates that when we treat education as a factor in a production function of gross sales of a multi-enterprise farm, the marginal product of education includes gains from both these effects, but in single commodity production functions only the worker effect is captured. Since farming in Punjab is in fact of a multi-enterprise nature and since we are dealing only with wheat the inference for our analysis is that the estimated coefficient for education is probably a serious underestimate. This view is substantiated by the results of Chaudhri's study (1969). He estimated a gross-sales production function for Indian agriculture and

---

[1/] Fins Welch (1970, p. 40).

obtained a coefficient of 0.08 for education, slightly more than double our estimate of 0.036.

Apart from this downward bias the coefficients for education in Indian agriculture (0.036 from our study and 0.08 from Chaudhri's study (1969) are much smaller compared to the coefficients of 0.4 and 0.14 for an intercountry study by Hayami (1969) and a Greek study by Yotopoulos (1968) respectively. However, we cannot always judge the importance of a factor of production by its size. A small mean of 2.49 years of schooling per household member in our sample means that it is basically primary education. We do not have cost estimates for one year of primary school education. Since there are almost no foregone earnings for this age group, it seems safe to assume that at least the private costs (to households) for this level of education are negligible. The value of marginal product of rupees 66.46 (computed from equation I and shown in the last column of Table 5.4) at the geometric mean of 2.49 years of education per household member, does not seem to be negligible.

Under somewhat restrictive assumptions we can proceed further to obtain an estimate for the capitalized value of 2.49 years of education per average household member. Let us make the following assumptions for this purpose.

1. The working age for the average household member is between 13 to 65 years of age, i.e., it is equal to 52 years.
2. The productive value of education lasts over this period.

3. The marginal value product of rupees 66.46 for a year of average education remains constant over the 52 year period.

With these assumptions the capitalized value for one year of education per household member is given by:

$$V = \frac{MVP}{\gamma}\left(1 - \frac{1}{(1+\gamma)^n}\right)$$

where

MVP is the constant annual value of the marginal product, γ is the relevant discount rate and $(1 + \gamma)^{-n}$ is the correction factor for finiteness of life, and approaches zero as n increases.

From this formula, for n = 52 and a discount rate of 10 percent, the capitalized value of one year of education per household member is estimated at rupees 659.95. Assuming that the marginal value of one year of education per household member is equal to the average value, the capitalized value of 2.49 years of education per average household member is equal to rupees 1643.27. At a lower discount rate of 5 percent this figure is equal to rupees 3073.73. The small amount of education of 2.49 years per household member thus does seem to be an important factor of production especially when we realize that our estimated marginal value product is a considerable underestimate. If in the above calculations we used the estimated coefficient of 0.08 from Chaudhri's (1969) study[1] the computed capitalized value

[1] As was pointed out earlier our estimate of 0.036 as a coefficient for education is probably a serious underestimate. If one could estimate for the farms to which our data pertains, a gross-sales production function for all crops, we should expect a coefficient close to Chaudhri's estimate. The estimate of the capitalized value of education obtained from Chaudhri's estimated coefficient would seem to be quite reasonable.

is more than double. The importance of education as a factor of production thus becomes obvious.

We, however, need to have a second look at our results with respect to animal capital. As was pointed out earlier, weak correlation between output and animal power, and high intercorrelations among other independent variables, are probably responsible for the imprecise estimate of the coefficient of animal power. The best estimate for this variable that we could obtain was 0.014 from regression I presented in Table 5.4. The magnitude of this coefficient still seems to be implausibly small and the estimated standard error is almost as large as the coefficient itself. But that is about as far as we can go in using regression techniques to assess the role of animal power in production. However, a rough estimate of the importance of animal power in wheat production could be obtained as the expenditure share of this variable in the total costs of wheat or alternatively in the total revenue at the geometric sample means. These two magnitudes for the three years pooled data (1967/68, 1968/69, and 1970/71) are 0.091 and 0.078 respectively. If we accept 0.078, the expenditure share of animal power in the total revenue, as a proxy estimate of output elasticity with respect to animal power the computed MVP for animal power at the geometric sample mean is rupees 0.99. This suggests that both animal power and education are important factors of production.

Cost Function Model

The cost function Model 2.10 has several advantages over the other two models. It yields direct estimates for the long-run cost function, a single estimate of returns to scale, and the use of year dummies enables us to study the yearly differences in the cost function. From this model, it is also possible to study whether the degree of returns to scale varies with the level of output. Since this model affords a single independent estimate of γ which is equal to the sum $\alpha_1 + \alpha_2 + \alpha_3$, the output elasticities for labor and land can be derived from the coefficients of logarithms of w and t respectively; and the coefficient for capital K can be obtained from this restriction. There is, however, one serious weakness in this model. As was pointed out earlier (Chapter II, p. 19), the omission of capital price from the estimating equation imparts biases to the coefficients of the other variables. Thus, the individual parameters of the production function are not accurately measured. In this section we explore these points by estimating this model. The results of least-squares regressions from Model 2.10 are summarized in Tables 5.5 and 5.6. The indirectly derived parameters of the production function from regression V (Table 5.5) and regression I (Table 5.6) are given in Table 5.7.

From Tables 5.5 and 5.6 we note that in all cases increasing returns to scale are indicated. The derived estimate of the output elasticity (Table 5.7) with respect to labor is quite comparable in magnitude to the direct production function estimates of regressions V, VI and VII, Table 5.1. However, the elasticities with respect to land

TABLE 5.5

ESTIMATES OF THE COST FUNCTION FOR NEW WHEAT, 1967/68-1970/71, PUNJAB, INDIA

Regression Number	Year	No. of Observations	Inter-cept	Coefficients of			R^2	SEE[a]	Returns to Scale
				Y	w	t			
I	1967/68	105	3.907 (0.516)	0.868 (0.023)	0.118 (0.119)	0.089 (0.085)	0.943	0.358	1.152*
II	1968/69	136	3.616 (0.635)	0.858 (0.029)	0.437 (0.127)	0.226 (0.104)	0.884	0.371	1.166*
III	1969/70	287	4.103 (0.305)	0.856 (0.019)	0.127 (0.079)	0.111 (0.051)	0.874	0.301	1.168*
IV	1970/71	128	4.800 (0.319)	0.910 (0.025)	0.244 (0.118)	0.046 (0.069)	0.937	0.219	1.099*
V	pooled	656	3.445 (0.188)	0.894 (0.011)	0.236 (0.051)	0.243 (0.035)	0.913	0.339	1.119*

Note: Regressions of logarithms of total cost (C) on logarithms of output (Y), wage rate (w) and per acre land rent (t) are estimated by least squares.

Standard errors of coefficients are in parentheses.

*Means that increasing returns to scale are indicated at 99 percent level of significance using F-ratio test.

a/ The standard errors of estimate are shown in natural logarithms of total costs measured in rupees.

TABLE 5.6

ESTIMATES OF THE COST FUNCTION FOR NEW WHEAT, 1967/68-1970/71, PUNJAB, INDIA

Regression Number	Inter-cept	Coefficients of D_1	D_2	D_3	ln Y	$(\ln Y)^2$	ln w	ln t	R^2	SEE[a]	Returns to Scale
I	3.879 (0.178)	0.402 (0.043)	0.416 (0.040)	0.327 (0.046)	0.865 (0.011)		0.211 (0.049)	0.121 (0.035)	0.926	0.313	1.156*
II A					0.852 (0.026)						1.175*
II B					0.860 (0.019)						1.162*
II	3.911 (0.190)	0.406 (0.044)	0.417 (0.040)	0.330 (0.046)			0.211 (0.050)	0.119 (0.035)	0.926	0.313	
II C					0.866 (0.016)						1.154*
II D					0.858 (0.014)						1.165*
III	3.815 (0.196)	0.396 (0.044)	0.410 (0.040)	0.321 (0.046)	0.899 (0.044)	-0.005 (0.006)	0.206 (0.050)	0.124 (0.035)	0.926	0.313	1.112*

Notes: Dependent variable was logarithm of total cost per farm.

Standard errors of coefficients are in parentheses.

*Means that increasing returns to scale are indicated at 99 percent level.

a/ Standard errors of estimate are shown in natural logarithms of total costs, measured in rupees.

and capital have magnitudes that appear to be implausible; they are small for land and large for capital. Our earlier reasoning in Chapter IV, page 58 (while discussing the results of the cost function model) is a logical explanation for these results. The omission of the price of capital from the cost function model biases downward the coefficient of logarithm of output $\frac{1}{\gamma}$ and in turn biases upward γ, the measure of returns to scale.[1/] This also biases downward the coefficient of land price (as well as output elasticity with respect to land).

An analysis of covariance test comparing separate yearly regressions I, II, III and IV with the pooled regression V (Table 5.5) gives an F-ratio of 10.51 with 12 and 640 degrees of freedom which is significant at 99 percent level implying that there are significant differences in the four years' cost functions. But comparing separate yearly regressions I, II, III, and IV (Table 5.5) with the pooled regression I (Table 5.6) which has the intercept-shifting year dummies in it, gives an F-ratio of 1.12 with 9 and 640 degrees of freedom, which is not significant at 90 percent level. On the basis of these tests, we conclude that the annual variations in the new wheat cost function and in the underlying production function have been neutral in character, that is, that only the intercept terms of the logarithmic functions changed from year to year but not the regression coefficients. Thus, the estimated coefficients of the dummy variables D_i (i = 1, 2, 3) for regressions I, II and III (Table 5.6) can be interpreted to represent percentage upward shifts in the yearly total cost functions relative to the year 1967/68 at given factor prices. The derived estimates

---

[1/] Since, as has already been argued, the price of capital and the output of wheat may be negatively correlated.

TABLE 5.7

PARAMETERS OF THE COBB-DOUBLAS PRODUCTION FUNCTION DERIVED FROM COST FUNCTION ESTIMATES, 1967/68-1970/71, PUNJAB, INDIA

Parameter	Regression V Table 5.5	Regression I Table 5.6
δ_1		-0.465
δ_2		-0.481
δ_3		-0.378
α_1	0.264	0.244
α_2	0.272	0.140
α_3	0.583	0.772
Returns to Scale	1.119	1.156

Notes: δ_i (i = 1, 2, 3) are the implicit coefficients for the year dummy variables in the production function and are derived from $-\frac{\delta_i}{\gamma}$, the estimated coefficients for the year dummy variables for 1968/69, 1969/70 and 1970/71 respectively, and $\frac{1}{\gamma}$, the estimated coefficient for logarithm of output in the cost function, regression I, (Table 5.6). They indicate percentage change in the efficiency parameter of the production function relative to the year 1967/68.

α_i (i = 1, 2, 3) are the implicit elasticities of output with respect to labor, land and capital K. They are derived from $\frac{1}{\gamma}$, $\frac{\alpha_1}{\gamma}$ and $\frac{\alpha_2}{\gamma}$, the estimated coefficients of logarithms of Y, w and t respectively in the cost function and the restriction

$$\gamma = \sum_{i=1}^{3} \alpha_i .$$

of δ_i (i - 2, 2, 3) from $-\frac{\delta_i}{\gamma}$ for regression I (Table 5.6) shown in Table 5.7 have negative signs and represent magnitudes in percentage terms by which the production function for years 1968/69, 1969/70 and 1970/71 was lower relative to 1967/68. These estimates correspond quite closely to the ones obtained from direct estimation of the Cobb-Douglas production function regression VII (Table 5.2).

In order to determine whether the degree of returns to scale varies with the level of output, two variants of the cost function (Model 2.10) were tried. In the first case, we divided the pooled 656 observations into four equal groups of 164 observations each, based on the ascending order of output per farm. Then by using slope dummies for each group, we allowed the coefficients of logarithms of output to vary across groups, while keeping the coefficients for logarithms of w and t and D_i (i = 1, 2, 3) equal in all groups. These estimates and the values of γ for the four groups (A, B, C, D) are presented in Table 5.6, where regression II is represented by groups IIA, IIB, IIC and IID. In this regression coefficients for logarithm of output (the reciprocals of these coefficients represent returns to scale) pertain to the output range represented by each individual group but the coefficients for the three dummy variables, logarithm of w and logarithm of t are common to all four groups (IIA, IIB, IIC and IID). In order to test whether the coefficient for logarithm of output and hence γ (the measure of returns to scale) vary among the four groups, we compare regression II represented by groups IIA, IIB, IIC and IID with the over-all regression I (Table 5.6). Analysis of covariance test gives an F-ratio of 0.68 with 3 and 646 degrees of freedom which is not significant at 90 percent level. These results, therefore, support the hypothesis that the degree of returns to scale does not vary with the level of output in the range of output observed.

In the second variant of the cost function, the degree of returns to scale is treated as a continuous function of output instead of breaking the sample into groups, assuming that variations in returns to scale are only of the neutral type. If we let γ (Y) be of the form

$$\gamma\ (Y) = \frac{1}{a_1 + a_1 \ \ln Y},$$

the cost function model (2.10) can be written

$$(5.1)\quad \ln C = b^* + a_o \ln Y + a_1 (\ln Y)^2 + \frac{\alpha_1}{\gamma} \ln w + \frac{\alpha_2}{\gamma} \ln t - \frac{\delta_i}{\gamma} D_i - \frac{u}{\gamma}.$$

In Equation 5.1 the degree of returns to scale is increasing, invariant or decreasing with the level of output if $a_1 \lesseqgtr 0$. Results of applying least-squares to Equation 5.1 are presented as regression III in Table 5.6. The coefficient a_1 in our estimates is not different from zero at 90 percent level of significance using two-tailed t test. Supported by our first test, we conclude that the degree of returns to scale does not vary with the level of output in the range of output observed. That is to say, there are no additional scale economies available from enlarging the size of wheat-producing farms in our sample. As to the size of these economies it has already been pointed out that the cost function model imparts an upward bias and that the estimates from the production function model indicate constant returns to scale. The hypothesis of constant returns to scale is also supported by the results from the profit function model in the next section where this issue will be taken up again.

Profit Function Model

In this section we present results of simultaneous estimation of the profit function and the labor demand function. Since these functions are written as functions of variables that are normally considered exogenous, the problem of simultaneous equation bias (to the extent it may be present) is avoided. In this sense, the indirectly derived production function estimates are also superior to our earlier direct production function estimates. They are also free from the type of biases introduced in our cost function estimates--biases due to the omission of capital price. In addition we derive estimates of output supply and labor demand elasticities with respect to output price, wage rate and the quantities of land and capital. Again the estimates pertain to new wheat for the four year period, 1967/68-1970/71.

For the purpose in hand, Equation 2.47 of the profit function model (Model I) was enlarged to include the year dummy variables for 1968/69, 1969/70 and 1970/71 to capture the effects due to weather, and so on. Then Equations 2.47 and 2.32 were jointly estimated using Zellner's method of estimation (1962). Since β_1 appears in both the equations a restriction was imposed that β_1 be equal in both equations. We also added to this restriction the assumption of constant returns to scale, that is, $\beta_2 + \beta_3 = 1$. These estimates are presented in Table 5.8 along with those obtained from the single-equation ordinary least squares. The application of this estimation procedure resulted in a significant reduction (about 12 percent) in the estimated standard errors as compared with those of single-equation least squares.

Before proceeding further we test the hypothesis of constant returns to scale in all inputs through the coefficients of land and capital[1/] in the profit function.[2/]

$$Ho: \beta_2 + \beta_3 = 1.$$

The computed F-ratio is 3716.18 with 1 and 1304 degrees of freedom. On statistical grounds we thus reject the hypothesis of constant returns to scale in favor of increasing returns to scale. Since, however, only mildly increasing returns to scale are indicated—the sum of estimated values of β_2 and β_3 is 1.048 from the unrestricted estimates and 1.056 with the equality restriction of β_1—we proceed with constrained estimation under the assumption of constant returns to scale. Constant returns to scale are also consistent with our earlier direct production function estimates. These results are presented in the last column of Table 5.8 and the parameters of the production function derived from them in Table 5.9.

[1/] See Lau and Yotopoulos (1972) for an explanation of this test.

[2/] See estimating equations in footnotes to Table 5.8, page 92.

TABLE 5.8

RESULTS OF JOINT ESTIMATION FOR NEW WHEAT OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION, 1967/68-1970/71, PUNJAB, INDIA

		Estimated Coefficients (Model I)			
			Zellner's Method with Restrictions		
Function	Parameter	Single Equation Ordinary Least Squares	Unrestricted	1 Restriction $\beta_1 = \beta_1$	2 Restrictions $\beta_1 = \beta_1$ $\beta_2 + \beta_3 = 1$
UOP Profit Function	λ	4.409 (0.333)	4.456 (0.301)	4.391 (0.304)	4.683 (0.292)
	δ_1	-0.408 (0.068)	-0.385 (0.061)	-0.376 (0.062)	-0.319 (0.060)
	δ_2	-0.391 (0.063)	-0.356 (0.056)	-0.349 (0.057)	-0.275 (0.053)
	δ_3	-0.239 (0.070)	-0.245 (0.063)	-0.198 (0.063)	-0.143 (0.063)
	β_1	-0.242 (0.079)	0.088 (0.072)	-0.302 (0.043)	-0.290 (0.043)
	β_2	0.701 (0.055)	0.688 (0.049)	0.697 (0.050)	0.682 (0.050)
	β_3	0.359 (0.056)	0.360 (0.050)	0.359 (0.051)	0.318 (0.050)
Labor Demand Function	β_1	-0.422 (0.054)	-0.422 (0.054)	-0.302 (0.043)	-0.290 (0.043)

Notes: The estimating equations are

$$\ln \pi = \lambda + \sum_{i=1}^{3} \delta_i D_i + \beta_1 \ln w + \beta_2 \ln L + \beta_3 \ln K$$

$$-\frac{wN}{\pi} = \beta_1$$

where D_i are year dummy variables with D_1, D_2, D_3 taking the value of one for only 1968/69, 1969/70, 1970/71 respectively and zero elsewhere. The remaining variables are as defined in Chapter III. Asymptotic standard errors are in parentheses.

TABLE 5.9

PRODUCTION FUNCTION ESTIMATES FOR NEW WHEAT, 1967/68-1970/71, PUNJAB, INDIA

Parameter		Direct Production Function Estimates: VI[a]	Direct Production Function Estimates: VII[a]	Indirect Estimates: Cost Function I[b]	Indirect Estimates: Profit Function[c] 1 Restriction $\beta_1 = \beta_1$	Indirect Estimates: Profit Function[c] 2 Restrictions $\beta_1 = \beta_1$, $\beta_2 + \beta_3 = 1$
	δ_1	-0.308	-0.473	-0.465		-0.221
	δ_2	-0.287	-0.454	-0.481		-0.189
	δ_3	-0.169	-0.396	-0.378		-0.104
Labor	α_1	0.163	0.181	0.244	0.231	0.224
Land	α_2	0.582	0.475	0.140	0.536	0.529
Capital K.	α_3	0.291	0.357	0.772	0.276	0.247
Sum of Elasticities $(\alpha_1 + \alpha_2 + \alpha_3)$		1.036	1.013	1.156	1.043	1.000

Notes: a/VI and VII are the regression numbers from Table 5.2.

b/I is the regression number in Table 5.7.

c/These indirect estimates are computed from the identities in Equation 2.30.

In Table 5.9 we have summarized the production function estimates for new wheat from the four years' pooled data, obtained from our three models. It is apparent that while the results obtained from the production function model and the profit function model are quite similar those derived from the cost function model are quite different from them. The output elasticity with respect to land is implausibly smaller and vice versa for output elasticity with respect to capital. In Table 5.10 we present the marginal value products of various inputs using output elasticities from Tables 5.9 and 5.2 and again we find that marginal value product of land from the cost function model is much smaller and that for capital much larger. The explanation for these results, as was argued earlier is that the omission of 'capital price' in estimating Equation 2.10 of the cost function model biases the coefficients of logarithm of output and logarithm of land rent downward resulting in a smaller derived coefficient for land. Since the coefficient for capital is obtained by subtracting the coefficients for labor and land from γ which is biased upward and since the coefficient of land is biased downward, the coefficient for capital is biased upward.

Output elasticities with respect to different inputs obtained from the direct production function estimates and indirectly derived from the profit function estimates presented in Table 5.9, are quite similar and compare quite favorably with the expenditure shares (Table 5.10) of the respective inputs in the total revenue or total costs calculated at the geometric means for the four years' data. The marginal value

TABLE 5.10

EXPENDITURE SHARES OF VARIOUS INPUTS AT SAMPLE GEOMETRIC MEANS IN TOTAL REVENUE AND TOTAL COST IN THE PRODUCTION OF NEW WHEAT, 1967/68-1970/71,[1/] PUNJAB, INDIA

Input	Share in Total Revenue	Share in Total Cost
Labor	0.213	0.241
Land	0.267	0.301
Capital, K	0.371	0.419
Capital, K_2	0.281	0.317
Fertilizer	0.071	0.080

[1/] Respective expenditure shares are calculated from the sample data.

TABLE 5.11

AVERAGE AND MARGINAL VALUE PRODUCTS FOR DIFFERENT INPUTS IN THE PRODUCTION OF NEW WHEAT, 1967/68-1970/71
(Calculated at geometric means)

Input	Geometric Means	Input Prices	Average Value Products	Marginal Value Products Using Output Elasticities From: (Table 5.9) Direct Production Function VI	VII	Cost Function I	Profit Function 1 Restriction	Profit Function 2 Restrictions	(Table 5.1) Regression VI	Regression VII
				rupees per unit of input						
Labor (hrs)	1636.00	0.76[a]	3.59	0.59	0.65	0.88	0.83	0.81	0.68	0.70
Land (acres)	7.85	198.34[b]	746.87	434.68	354.76	104.56	400.32	395.09	457.83	373.44
Capital K (R_s)	2165.30		2.71	0.79	0.97	2.09	0.75	0.67		
Capital K_2 (R_s)	1636,00		3.59						0.58	0.88
Fertilizer (R_s)	411.69		14.24						0.94	0.98
Output (quintals)	76.71									
Output Price[c] (R_s/quintal)	76.43									

a /Wage rate per hour.
b /Land rent per acre.
c /Sample arithmetic mean.

products for different inputs obtained by using these output elasticities from Table 5.9 and 5.1 are compared for various regressions and with their opportunity prices in Table 5.11. From these comparisons, it seems that our production function estimates obtained directly from the production function model as well as those derived indirectly from the profit function model are quite reasonable. The indirect estimates derived from the profit function formulation, however, have the advantage of being statistically consistent. In view of their consistency property, we consider the estimates presented in the last column of Table 5.9 as our best production function estimates of new wheat production function. Moreover, because these estimates are based on four years' data, they should have better predictive value than those obtained from a single cross-section.

It should also be noted that the coefficients δ_i (i = 1,2,3) for the dummy variables for the years after 1967/68, obtained from the profit function model constrained to have constant returns to scale (shown in last column of Table 5.9) have considerably smaller absolute magnitudes than those obtained from direct production function estimates or derived from the cost function model. This may be the result of superior estimating properties of the profit function model. We take these as more reliable estimates of the downward shift in the production function due to adverse weather, defective seed quality and so on, in the three years after 1967/68.

In addition to the advantage that indirect estimates of the production function parameters derived from the profit function are statistically consistent, we can also obtain a number of other important elasticity estimates from the profit function estimates of Table 5.8. Next we derive these estimates using parameter estimates from the last column of Table 5.8.

Let the labor demand function (2.32) be written as:

$$N = -\frac{\beta_1 \pi^*}{w'} = -\frac{\beta_1 \pi}{w}$$

or

(5.2) $\ln N = \ln(-\beta_1) + \ln \pi - \ln w$[1/]

or

$$\ln N = \ln(-\beta_1) + \ln \pi^* - \ln w'$$

From Equation 5.2 and by using profit function estimates of last column in Table 5.8, the labor demand elasticities with respect to wage rate, land L, capital K and price of output p are obtained as follows:

(5.3) $$\frac{\partial \ln N}{\partial \ln w} = \frac{\partial \ln \pi}{\partial \ln w} - 1$$

$$= \beta_1 - 1 = -1.290$$[2/]

(5.4) $$\frac{\partial \ln N}{\partial \ln L} = \frac{\partial \ln \pi}{\partial \ln L} = \beta_2 = 0.682$$[2/]

[1/] Note that $\ln \pi$ is the estimating equation (logarithmic profit function) shown in notes to Table 5.8, page 92.

[2/] Note that β_1 in (5.3), β_2 in (5.4) and β_3 in (5.5) are obtained by differentiation of the estimating equation (logarithmic profit function) shown in notes to Table 5.8 on page 92, with respect to wage rate w, land L, and capital K respectively and their estimated values are used from the last column of Table 5.8.

(5.5) $$\frac{\partial \ln N}{\partial \ln K} = \frac{\partial \ln \pi}{\partial \ln K} = \beta_3 = 0.318$$ [1/]

(5.6) $$\frac{\partial \ln N}{\partial \ln p} = \frac{\partial \ln N}{\partial \ln w'} \cdot \frac{\partial \ln w'}{\partial \ln p} = 1.290$$ [2/]

All these elasticity estimates have the signs we would expect on theoretical grounds. From (5.3) we see that price elasticity of demand for labor is negative and indicates that demand is quite responsive to wage levels. In response to a one percent increase in wage rate holding quantities of land and capital as constant, an average farm reduces labor use by 1.29 percent. Positive responses for labor demand to increases of land and capital and output price have important implications for labor absorption in wheat farming. On an average farm a one percent increase of wheat land holding wage rate and quantity of capital as constant, employs 0.682 percent more labor; one percent increase in capital holding wage rate and quantity of land as constant, employs 0.318 percent more labor and one percent increase in the price of wheat holding wage rate, land and capital as constant, results in 1.29 percent increase in labor use.

In order to calculate the output responses of the firm Equation 2.27 can be written as output supply function:

[1/] *Ibid.*, p. 98.

[2/] Since $w' \equiv \frac{w}{p}$, by definition.

$$(5.7) \qquad Y = \pi^* + w' N^*$$

$$= \pi^* (1-\beta_1) \text{--by a substitution of } N^* \text{ from (2.32).}$$

or

$$(5.8) \qquad \ln Y = \ln \pi^* + \ln (1-\beta_1).$$

The elasticity of output supply with respect to the normalized wage rate (using parameter estimates from last column of Table 5.8) is given by:

$$(5.9) \qquad \frac{\partial \ln Y}{\partial \ln w'} = \frac{\partial \ln \pi^*}{\partial \ln w'} = \beta_1 = -0.290,$$

which shows a relatively inelastic response. This finding along with an elastic response of demand for labor with respect to wage rate is of great importance. A one percent increase in wage rate holding quantities of land and capital as constant results in 1.29 percent reduction in labor use and 0.29 percent reduction in output.

From (5.8) output supply response with respect to output price is given by

$$(5.10) \qquad \frac{\partial \ln Y}{\partial \ln p} = \frac{\partial \ln Y}{\partial \ln w'} \; \frac{\partial \ln w'}{\partial \ln p} = 0.290$$

This finding is also important. Not only does it show a positive supply response to wheat price, but the magnitude is important for any effort to use the output price variable as a policy instrument for inducing increased supply of wheat.

From (5.8) we can also obtain the reduced form elasticities with respect to land and capital using parameter estimates presented in the last column of Table 5.3.

(5.11) $$\frac{\partial \ln Y}{\partial \ln L} = \frac{\partial \ln \pi^*}{\partial \ln L} = \beta_2 = 0.682$$

(5.12) $$\frac{\partial \ln Y}{\partial \ln K} = \frac{\partial \ln \pi^*}{\partial \ln K} = \beta_3 = 0.318$$

These elasticities indicate the output response of the average farm with respect to exogenous increases in land and capital respectively, holding the normalized wage rate and not the quantities of labor as constant. A given increase in the quantity of land (capital) shifts upward the marginal productivity curves of labor and other factors of production. As a result more of these inputs are employed than before. Thus, holding wage rate constant (but not the quantities of labor) a one percent expansion in wheat land will result in 0.682 percent increase in wheat output and one percent increase in capital will result in 0.318 percent increase in wheat output. For policy purposes their use is rather straightforward contrary to the output elasticities with respect to various inputs obtained from a production function, which measure their effect holding other input levels as constant.

Lastly we try to reassess the annual differences in the efficiency parameter of the production function relative to 1967/68. These estimates are computed from the definitional identiries in (2.30) and (2.46) by using the estimates for the intercept term and year dummies for the profit function presented in the last column of Table 5.8.

Since the output price has been kept constant at 76 rupees per quintal for the period under study it should not create any variation in the intercept of the profit function. The coefficients of the year dummies thus reflect differences due to weather or changes in seed quality, etc. From the estimated coefficients for the year dummies presented in the last column of Table 5.8, the computed values of the yearly decline in the efficiency parameter of the production function relative to 1967/68 were 22.1 percent, 18.9 percent and 10.4 percent for the years 1968/69, 1969/70 and 1970/71 respectively. These values are shown in the last column of Table 5.9. These estimates are considerably smaller than those obtained from the production function model and the cost function model. Yet they reflect considerable decline in the production function after 1967/68. Whether this is likely to be a temporary phenomena or a continuous technological regression in the production of new wheats should perhaps be investigated by agronomists and plant breeders.

Summary

From the statistical results presented in this chapter the following substantive conclusions seem to follow:

1. At the firm level there appear to be mildly increasing returns to scale in wheat production. But their magnitude is so close to unity that any definitive statement against constant returns to scale is not possible. Furthermore since the degree of returns to scale does not vary with the

output level no additional scale economies from enlargement of farm size are possible.

2. Annual variations in the wheat production function may well be neutral in character; that is they appear only through the displacement of the efficiency parameter and do not involve a change in the marginal rates of substitution between different inputs. The decline in the efficiency parameter of the production function after 1967/68 could have occurred because of adverse weather, defective seed quality, addition of inferior land to wheat production, or technological regression in the production of new wheats. Estimates of this decline from our data, obtained from the profit function formulation relative to 1967/68 are of the order of 22.1 percent for 1968/69, 18.9 percent for 1969/70 and 10.4 percent for 1970/71.

3. From (2) it follows that the long-run cost function shifted upward relative to 1967/68. These shifts as indicated by Equation I (Table 5.6) are of the order of 40.2 percent for 1968/69, 41.6 percent for 1969/70 and 32.7 percent for 1970/71.

4. A conclusion of methodological interest follows from these analyses: the direct application of least-squares for estimation of Cobb-Douglas production function compares quite well (Table 5.9) with the indirect estimation via the profit-function formulation. Thus for well specified production

functions and if the data are good, application of single equation least-squares may be adequate.

5. Estimates for the production function coefficients and the labor demand and output supply elasticities with respect to wage rate, output price and quantities of land and capital are all consistent with economic theory and have plausible values.

CHAPTER VI

EMPIRICAL RESULTS AND THEIR INTERPRETATION: RELATIVE ECONOMIC EFFICIENCY--SMALL VERSUS LARGE FARMS

In this chapter we have the specific purpose of comparing the economic efficiency of small and large wheat farms. It is important to point out again at this stage that this efficiency analysis is specific to the wheat crop alone and does not include all enterprises.[1] Since, however, wheat is the dominant crop[2] in winter season, it could be argued that the conclusions would hold to some degree for the whole farm organization.

Efficiency comparisons of small and large farms have obvious policy implications for agrarian reorganization, land redistribution, and ceilings on land ownership. In India these questions are (and have been over the past two decades) important policy issues. In spite of numerous researches[3] the question of relative efficiency of small and large farms has remained unsettled. The findings of Lau and Yotopoulos (March 1971 and Memorandum 104) that small farms are more

---

[1] See footnote 1 on page 2.

[2] During 1970/71 winter season, 83 percent of the total farm area in our sample was planted to wheat. During the winter season of 1968/69, 74 percent of the total cropped area was planted to wheat in the Ferozepur sample.

[3] For list of references and our earlier discussion on this point see footnote 3 in Chapter II, page 23. Also see P. K. Bardhan (1972) and S. S. Johl (April 1972).

efficient economically are somewhat more conclusive. However, they used data for the mid-fifties. Because Indian agriculture has been undergoing rapid changes, we use more recent data and follow their approach to study whether smaller or larger[1] wheat farms are more efficient economically.

Before proceeding further we restate briefly the various efficiency concepts developed in Chapter II. Differences in technical efficiency of the two firms specifically mean neutral differences in the efficiency parameters of the production functions. This implies that non-neutral differences in the production functions of small and large farms are ruled out.[2] Thus the firm which produces more output from given amounts of inputs than another is technically more efficient. If a firm is able to maximize profits, i.e., is able to equate the value of marginal product of its variable input (in this case labor) to its price, the firm is said to be price-efficient. This is the concept of absolute price (or allocative) efficiency. Differences in price efficiency among firms exist if they are unsuccessful to varying degrees in their attempts to maximize profits. Over-all economic efficiency thus is the result of its two components: technical efficiency and price efficiency. The two firms could be unequally efficient economically because of differences in either or

---

[1] To keep this analysis comparable to Lau and Yotopoulos, ten acres of wheat is used as the upper limit for small farms.

[2] In the next section of this chapter, we test the hypothesis of non-neutral variations in the production functions (technology) of small and large farms.

both of these components. Also the two firms could have equal over-all economic efficiency even when they have differences in technical or price efficiency or both. The relatively more economically efficient firm will have larger profits for a given range of input prices. We use our profit function (Models II and III) to study these differences among small and large wheat farms in Punjab over the period 1967/68 to 1970/71.

Production Function for Small and Large Wheat Farms

Efficiency comparisons of small and large farms are based on the assumption of no non-neutral differences in the technology of small and large farms. In order to pursue this analysis we first test the validity of this assumption.

In Table 6.1, we compare the production function estimates in the farm of separate regressions of small and large farms and over-all regressions for the period 1967/68 to 1970/71. The coefficient for the size dummy variable[1/] D^L is not significantly different from zero at 90 percent level using a two-tailed t test, either when fertilizer is treated as a separate factor of production (regression I) or when capital input includes fertilizer (regression IV). Analyses of co-variance comparing separate regressions II and III with I and separate regressions V and VI with IV give F-ratios 0.43 with 7 and 640 degrees of freedom and 0.10 with 6 and 642 degrees of freedom.

[1/] The dummy variable D^L has a value of one for farms with ten or more acres in wheat (large farms) and zero for the remaining farms (small farms).

TABLE 6.1

ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68-1970/71, PUNJAB, INDIA

Regression Number	I	II	III	IV	V	VI
Farm Class	Over-all	Small	Large	Over-all	Small	Large
No. of Observations	656	334	322	656	334	322
Constant	0.302	0.297	0.241	-0.077	-0.051	-0.107
	(0.253)	(0.338)	(0.437)	(0.266)	(0.359)	(0.446)
D^L	-0.020			-0.017		
	(0.042)			(0.041)		
D_1	-0.301	-0.283	-0.305	-0.310	-0.305	-0.314
	(0.048)	(0.063)	(0.080)	(0.047)	(0.062)	(0.079)
D_2	-0.283	-0.275	0.279	-0.289	-0.291	-0.282
	(0.044)	(0.060)	(0.071)	(0.043)	(0.060)	(0.071)
D_3	-0.173	-0.191	-0.131	-0.171	-0.194	-0.141
	(0.048)	(0.064)	(0.081)	(0.048)	(0.064)	(0.081)
Labor	0.191	0.212	0.165	0.164	0.172	0.155
	(0.041)	(0.059)	(0.060)	(0.041)	(0.060)	(0.060)
Land	0.619	0.615	0.615	0.587	0.592	0.578
	(0.045)	(0.060)	(0.072)	(0.045)	(0.061)	(0.073)
Capital (K or K_2)	0.159	0.126	0.207	0.290	0.278	0.302
	(0.040)	(0.055)	(0.058)	(0.042)	(0.062)	(0.060)
Fertilizer	0.066	0.083	0.046			
	(0.014)	(0.021)	(0.019)			
$\bar{R}^2$	0.915	0.874	0.641	0.915	0.873	0.647
SEE[a]	0.347	0.372	0.321	0.345	0.372	0.318
Returns to scale	1.035	1.036	1.033	1.041	1.042	1.035
F-ratio[b]	0.33	2.17	0.55	1.03	2.00	0.50

Notes: Equations linear in logarithms are estimated by least squares.

Dependent variable is output of wheat in physical units.

D^L is a dummy variable with a value of one for farms with ten or more acres in wheat (large farms) and zero for the remaining farms (small farms).

D_i (i=1,2,3) are dummy variables with value of one for 1968/69, 1969/70, 1970/71 respectively and zero otherwise.

Capital input K does and K_2 does not include fertilizer.

Standard errors of coefficients are in parentheses.

a/ Standard errors of estimate are in natural logarithms of wheat output measured in quintals.

b/ This F-ratio is calculated to test the hypothesis of constant returns to scale.

$\bar{R}^2$ is the coefficient of determination adjusted for degrees of freedom.

These F-ratios are not significant at the 90 percent level. These results mean that the Cobb-Douglas production function for new wheat does not vary between smaller and larger wheat farms either in the efficiency parameter or in the production elasticities. Put differently, from these data we cannot reject the hypotheses that there exist neither neutral nor non-neutral differences between large and small farms and that the production functions for small and large wheat farms are identical.

There appears to be no evidence against the hypothesis of constant returns to scale for farms less than ten acres, larger than ten acres and for all farms in the sample. It should also be pointed out here that in Chapter V, the results from the cost function model--when the sample is split into four groups, and also when the degree of returns to scale is treated as a continuous function of output--indicate that the degree of returns to scale does not vary with the level of output. Output elasticities with respect to all inputs seem to be quite reasonable. The coefficients for year dummies indicate some downward shifts from the year 1967/68. Some possible explanations for these results were offered in Chapter V.

Relative Efficiency: Profit Function Formulation

There are different policy implications associated with each component of differences (technical efficiency or price efficiency) in economic efficiency of small and large farms. For example, the finding that small farms are more technical efficient and that both small and large farms are absolute price efficient could lead to the conclusion that small farms serve the national interest better (leaving aside the equity or equalitarian considerations). If we find that larger farms are more price-efficient, it has implications for policies pertaining to extension services; for example, policies which improve market information for smaller farmers may improve their allocative efficiency. And if we find no differences in either the technical or price efficiency parameters of the two kinds of farms, the agrarian policies could be based on social and political considerations independent of efficiency considerations. It is thus important to obtain knowledge of the source of differences (technical or price) in economic efficiency. The profit function (Model II) of Chapter II is designed to provide this knowledge.

The estimation results of this model (Model II: Equation 2.46 and 2.48) using Zellner's method (1962) for each of the four years 1967/68 to 1970/71 are presented in Tables 6.2, 6.3, 6.4 and 6.5, respectively. Similar results for the four-year combined data based on (Model III: Equations 2.46 and 2.48) are presented in Table 6.6. In order to provide answers to the questions of relative efficiency posed above we carry out the following statistical tests:[1/]

(1) The hypothesis of equal relative economic efficiency of small and large wheat farms:

[1/] The results of all these tests are presented in Table 6.7.

TABLE 6.2

RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1967/68, PUNJAB, INDIA

Function	Parameter	Estimated Coefficients: Single-Equation Ordinary Least Squares	Zellner's Method with Restrictions (Model II): Unrestricted	1 Restriction $\beta_1^L = \beta_1^S$	2 Restrictions $\beta_1^L = \beta_1$, $\beta_1^S = \beta_1$	3 Restrictions $\beta_1^L = \beta_1$, $\beta_2 + \beta_3 = 1$, $\beta_1^S = \beta_1$
UOP Profit Function	λ	3.799	3.433	3.446	3.019	3.885
		(0.748)	(0.641)	(0.641)	(0.667)	(0.636)
	δ^L	-0.141	-0.064	-0.112	-0.138	0.093
		(0.144)	(0.137)	(0.123)	(0.131)	(0.115)
	β_1	0.107	0.263	0.262	-0.244	-0.236
		(0.159)	(0.136)	(0.136)	(0.034)	(0.034)
	β_2	0.614	0.506	0.506	0.520	0.537
		(0.115)	(0.098)	(0.098)	(0.104)	(0.109)
	β_3	0.487	0.564	0.563	0.599	0.462
		(0.125)	(0.107)	(0.107)	(0.113)	(0.109)
Labor Demand Function	β_1^L	-0.221	-0.221	-0.274	-0.244	-0.236
		(0.075)	(0.075)	(0.035)	(0.034)	(0.034)
	β_1^S	-0.289	-0.289	-0.274	-0.244	-0.236
		(0.040)	(0.040)	(0.035)	(0.034)	(0.034)
	R^2	0.923				

(Notes continued on next page)

Notes: The estimating equations are:

$$\ln \pi = \lambda + \delta^L D^L + \beta_1 \ln w + \beta_2 \ln \mathcal{L} + \beta_3 \ln K$$

$$\frac{-wN}{\pi} = \beta_1^{\mathcal{L}} D^{\mathcal{L}} + \beta_1^S D^S$$

where:

π is profit (total receipts less wage bill)

w is money wage rate

$D^{\mathcal{L}}$ is a dummy variable taking the value of one if wheat area is greater than ten acres and zero otherwise.

D^S is a dummy variable taking the value of one if wheat area is less than ten acres and zero otherwise.

N is labor in hours per farm used in wheat production.

$\mathcal{L}$ is land in acres used for producing wheat.

K is total costs of capital services for wheat per farm.

Asymptotic standard errors are in parentheses.

TABLE 6.3

RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1968/69, PUNJAB, INDIA

Function	Parameter	Estimated Coefficients				
			Zellner's Method with Restriction (Model II)			
		Single-Equation Ordinary Least Squares	Unrestricted	1 Restriction $\beta_1^L = \beta_1^S$	2 Restrictions $\beta_1^L = \beta_1$ $\beta_1^S = \beta_1$	3 Restrictions $\beta_1^L = \beta_1$ $\beta_2 + \beta_3 = 1$ $\beta_1^S = \beta_1$
UOP Profit Function	λ	4.115	3.714	3.725	3.391	3.309
		(0.994)	(0.692)	(0.691)	(0.673)	(0.655)
	δ^L	-0.041	0.049	0.026	0.061	0.015
		(0.160)	(0.133)	(0.111)	(0.109)	(0.070)
	β_1	-0.507	0.024	0.024	-0.381	-0.381
		(0.207)	(0.144)	(0.144)	(0.041)	(0.041)
	β_2	0.713	0.514	0.514	0.477	0.498
		(0.179)	(0.124)	(0.124)	(0.122)	(0.114)
	β_3	0.334	0.454	0.454	0.495	0.503
		(0.170)	(0.118)	(0.118)	(0.116)	(0.114)
Labor Demand Function	β_1^L	-0.406	-0.406	-0.421	-0.381	-0.381
		(0.065)	(0.065)	(0.043)	(0.041)	(0.041)
	β_1^S	-0.433	-0.433	-0.421	-0.381	-0.381
		(0.059)	(0.059)	(0.043)	(0.041)	(0.041)
	R^2	0.771				

Notes: The estimating equations and the definitions of variables are as in Table 6.2. Asymptotic standard errors are in parentheses.

TABLE 6.4

RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1969/70, PUNJAB, INDIA

		Estimated Coefficients				
			Zellner's Method with Restrictions (Model II)			
Function	Parameter	Single-Equation Ordinary Least Squares	Unrestricted	1 Restriction $\beta_1^L = \beta_1^S$	2 Restrictions $\beta_1^L = \beta_1$, $\beta_1^S = \beta_1$	3 Restrictions $\beta_1^L = \beta_1$, $\beta_2 + \beta_3 = 1$, $\beta_1^S = \beta_1$
UOP Profit Function	λ	4.651	4.748	4.744	4.744	4.694
		(0.477)	(0.411)	(0.410)	(0.418)	(0.408)
	δ^L	0.093	0.136	0.142	0.142	0.099
		(0.108)	(0.098)	(0.093)	(0.094)	(0.055)
	β_1	-0.278	-0.058	-0.058	-0.248	-0.247
		(0.124)	(0.106)	(0.106)	(0.081)	(0.081)
	β_2	0.740	0.714	0.714	0.716	0.742
		(0.098)	(0.085)	(0.085)	(0.086)	(0.072)
	β_3	0.259	0.260	0.260	0.256	0.257
		(0.082)	(0.070)	(0.070)	(0.072)	(0.072)
Labor Demand Function	β_1^L	-0.501	-0.501	-0.482	-0.248	-0.247
		(0.153)	(0.153)	(0.122)	(0.081)	(0.081)
	β_1^S	-0.449	-0.440	-0.482	-0.248	-0.247
		(0.204)	(0.204)	(0.122)	(0.081)	(0.081)
	R^2	0.776				

Notes: The estimating equations and the definitions of variables are as in Table 6.2. Asymptotic standard errors are in parentheses.

TABLE 6.5

RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1970/71, PUNJAB, INDIA

Function	Parameter	Estimated Coefficients: Single-Equation Ordinary Least Squares	Zellner's Method With Restrictions (Model II): Unrestricted	1 Restriction $\beta_1^L = \beta_1^S$	2 Restrictions $\beta_1^L = \beta_1$, $\beta_1^S = \beta_1$	3 Restrictions $\beta_1^L = \beta_1$, $\beta_2 + \beta_3 = 1$, $\beta_1^S = \beta_1$
UOP Profit Function	λ	2.859	3.287	3.291	3.386	3.438
		(0.641)	(0.595)	(0.594)	(0.581)	(0.576)
	δ^L	0.056	-0.048	-0.051	-0.057	-0.010
		(0.110)	(0.104)	(0.102)	(0.101)	(0.059)
	β_1	-0.481	-0.184	-0.184	-0.255	-0.254
		(0.189)	(0.176)	(0.175)	(0.025)	(0.025)
	β_2	0.477	0.496	0.496	0.512	0.477
		(0.131)	(0.121)	(0.121)	(0.117)	(0.110)
	β_3	0.581	0.539	0.539	0.523	0.523
		(0.112)	(0.103)	(0.103)	(0.100)	(0.100)
Labor Demand Function	β_1^L	-0.234	-0.254	-0.259	-0.255	-0.254
		(0.051)	(0.051)	(0.025)	(0.025)	(0.025)
	β_1^S	-0.304	-0.265	-0.259	-0.255	-0.254
		(0.048)	(0.046)	(0.025)	(0.025)	(0.025)
	R^2	0.870				

Notes: The estimating equations and the definitions of variables are as in Table 6.2. Asymptotic standard errors are in parentheses.

TABLE 6.6

RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1967/68-1970/71, PUNJAB, INDIA

Function	Parameter	Estimated Coefficients: Single-Equation Ordinary Least Squares	Zellner's Method with Restrictions (Model III): Unrestricted	1 Restriction $\beta_1^L = \beta_1^S$	2 Restrictions $\beta_1^L = \beta_1$, $\beta_1^S = \beta_1$	3 Restrictions $\beta_1^L = \beta_1$, $\beta_2 + \beta_3 = 1$, $\beta_1^S = \beta_1$
UOP Profit	$\ln A^S_*$	4.405	4.479	4.475	4.410	4.568
		(0.334)	(0.301)	(0.301)	(0.303)	(0.297)
	δ^L	-0.025	-0.021	-0.012	-0.015	0.075
		(0.059)	(0.056)	(0.053)	(0.054)	(0.038)
	δ_1	-0.411	-0.384	-0.384	-0.377	-0.336
		(0.068)	(0.061)	(0.061)	(0.062)	(0.060)
	δ_2	-0.393	-0.353	-0.353	-0.347	-0.305
		(0.063)	(0.057)	(0.057)	(0.057)	(0.054)
	δ_3	-0.242	-0.241	-0.240	-0.200	-0.163
		(0.071)	(0.064)	(0.064)	(0.063)	(0.061)
	β_1	-0.243	-0.085	-0.085	-0.279	-0.271
		(0.079)	(0.072)	(0.072)	(0.042)	(0.042)
	β_2	0.709	0.690	0.690	0.700	0.663
		(0.058)	(0.053)	(0.052)	(0.053)	(0.050)
	β_3	0.359	0.358	0.358	0.358	0.337
		(0.056)	(0.051)	(0.051)	(0.051)	(0.050)
Labor Demand Function	β_1^L	-0.411	-0.412	-0.379	-0.279	-0.271
		(0.078)	(0.078)	(0.052)	(0.042)	(0.042)
	β_1^S	-0.351	-0.346	-0.379	-0.279	-0.271
		(0.078)	(0.077)	(0.052)	(0.042)	(0.042)

Notes on following page.

TABLE 6.6 (continued)

Notes: The estimating equations are:

$$\ln \pi = \ln A_*^S + \delta^L D^L + \sum_{i=1}^{3} \delta_i D_i + \beta_1 \ln w + \beta_2 \ln L + \beta_3 \ln K$$

$$-\frac{wN}{\pi} = \beta_1^L D^L + \beta_1^S D^S$$

where the variables are as defined earlier in Table 6.2.

Asymptotic standard errors are in parentheses.

TABLE 6.7

TESTING OF STATISTICAL HYPOTHESES, MODEL II AND MODEL III

Maintained Hypothesis	Tested Hypothesis	Computed F-Ratio 1967/68	1968/69	1969/70	1970/71	1967/68 to 1970/71
	(1) $\delta^L = 0$	F(1,203)=0.22	F(1,265)=0.14	F(1,567)=1.93	F(1,249)=0.23	F(1,1302)=0.15
	(2) $\beta^L = \beta^S$	F(1,203)=0.64	F(1,265)=0.10	F(1,567)=0.04	F(1,249)=0.02	F(1,1302)=0.34
	(3) $\delta^L = 0$, $\beta^L = \beta^S$	F(2,203)=0.73	F(2,265)=0.08	F(2,567)=1.20	F(2,249)=0.14	F(2,1302)=0.20
$\beta_1^L = \beta_1^S$	(4) $\beta_1^L = \beta_1$	F(2,203)=7.72	F(2,265)=4.71	F(2,567)=3.44	F(2,249)=0.10	F(2,1302)=5.58
$\beta_1^L = \beta_1^S$	(5) $\beta_1^S = \beta_1$	F(2,203)=7.72	F(2,265)=4.71	F(2,567)=3.44	F(2,249)=0.10	F(2,1302)=5.58
	(6) $\beta_2+\beta_3=1$	F(1,203)=839.81	F(1,265)=373.61	F(1,567)=384.94	F(1,249)=306.41	F(1,1302)=1812.13

Note.--Critical F-ratios are: $F_{0.10}(1, \infty) = 2.71$; $F_{0.05}(1, \infty) = 3.84$; $F_{0.01}(1, \infty) = 6.63$

$F_{0.10}(2, \infty) = 2.30$; $F_{0.05}(2, \infty) = 3.00$; $F_{0.01}(2, \infty) = 4.61$

$$Ho: \ \delta^L = 0,$$

that is, $\ln (A^L_*/A^S_*) = 0$ or $A^L_* = A^S_*$. From Table 6.7 we see that we cannot reject this hypothesis at the 90 percent level of significance for any of the four years separately as well as for the four years combined. Thus the conclusion that small and large farms have equal over-all economic efficiency is inescapable.

(2) The hypothesis of equal relative price efficiency:

$$Ho: \ \beta^L_1 = \beta^S_1$$

The meaning of this test is whether in their labor demand function large and small farms have the same price efficiency parameters. This hypothesis also cannot be rejected at the 90 percent level of significance (Table 6.7), for any of the four years separately or for the four year pooled data. Thus the conclusion is that with respect to labor, small and large farms have been equally successful (or unsuccessful) in maximizing profits, that is, they have had the same price-efficiency parameters during each of the four years studied.

(3) The joint hypotheses of equal relative technical and price efficiency:

$$Ho: \ \delta^L = 0 \text{ and}$$

$$\beta^L_1 = \beta^S_1.$$

The meaning of these tests is whether large and small farms have equal over-all economic efficiency and at the same time have the same price efficiency parameters β_1^L and β_1^S in labor demand functions. This hypothesis also cannot be rejected at the 90 percent level of significance for any of the four years individually or for the combined data. This confirms the conclusions in (1) and (2) above, that is, the small and large farms were equally efficient economically and had equal price efficiency during each of the farm years and on an average for the four years. This implies that they also had equal technical efficiency.

(4) Next we turn to the hypotheses of :

(a) Absolute price-efficiency of large farms,

$$Ho: \beta_1^L = \beta_1, \text{ and}$$

(b) Absolute price-efficiency of small farms,

$$Ho: \beta_1^S = \beta_1.$$

For the first two years 1967/68 and 1968/69 and for the four years pooled data we reject these hypotheses at 99 percent level of significance and for the year 1969/70 at 95 percent level of significance. But, for the latest year 1970/71 we cannot reject these hypotheses at 90 percent level of significance. This means that, during the years 1967/68 and 1968/69, both small and large farms were unsuccessful in their attempts to maximize profits in the sense of equating the value of marginal product of labor to its wage rate. During the year 1969/70, they were still not successful in maximizing profits, but we reject the hypothesis of profit maximization less strongly than for the years 1967/68 and 1968/69. For the year 1970/71, however, we find that both small and large farms were able to maximize profits. Later we discuss the meaning of these results with respect to the profit-maximizing behavior of the wheat producers.

(5) Lastly we test the hypothesis of constant returns to scale in all factors of production:

$$Ho: \beta_2 + \beta_3 = 1.$$

This hypothesis is rejected at the 99 percent level of significance in all cases. The sum $\beta_2 + \beta_3 > 1$ for the years 1967/68, 1970/71 and for the four-year pooled data. But $\beta_2 + \beta_3 < 1$ for the years 1968/69 and 1969/70. These differences from unity are quite small in either case. Also, perhaps slightly increasing returns for the years 1967/68 and 1970/71 resulted because a larger number of observations (as argued before, page 66) for these years were below the respective sample averages. Thus even though on statistical grounds we do--in some cases--reject the hypothesis of constant returns to scale, we do not find convincing evidence favoring the hypothesis of increasing returns in wheat farming in Punjab. The results of the first three statistical hypotheses--(1), (2) and (3)--presented above show rather conclusively that small and large wheat farms have no differences in their over-all economic efficiency, technical efficiency and price (or allocative) efficiency.

The view that small and large farmers have the same economic acumen or motivation seems to hold. Because wheat is a dominant enterprise on these farms, one can argue that these conclusions would perhaps be equally applicable when all enterprises on these farms are considered. There are important policy implications of these findings. The most substantive one is that policies with respect to land redistribution and ceilings on ownership of land can be based on social and political considerations without worrying about the farm size efficiency considerations. Another important implication is that governmental policies with respect to pricing, supply of agricultural inputs, marketing facilities, provision of credit and extension services and so on need not favor either large or small farms on the basis of their economic efficiency or its components of technical efficiency or price efficiency. This view is reinforced by the absence of any strong evidence against constant returns to scale.

The results of statistical test (4) have interesting implications with respect to the profit-maximizing behavior (or rationality) of the wheat producers. They have a bearing on earlier price or allocative studies.[1] The results appear to indicate the existence of a short-period disequilibrium between the profit-maximizing attempts and the actual results achieved by wheat producers; this disequilibrium was created by shifts in the labor demand function resulting from the

---

[1]See Hopper (Aug. 1965), Khusro (Oct. 1964), Schultz (1964), Sahota (Aug. 1968) and Lau and Yotopoulos (March 1971 and Memo 104).

introduction of high-yielding wheats. During the first two years 1967/68, 1968/69 the producers were not in equilibrium in the sense of equating the marginal value product of labor to its opportunity cost. For the third year 1969/70 we reject the hypotheses of absolute price-efficiency at 95 percent level of significance (but not at 99 percent as for the years 1967/68 and 1968/69), that is, not as strongly as during the first two years. And finally during the last year 1970/71, we cannot reject the hypotheses of absolute price efficiency, that is, we find that producers on the average (both small and large) were able to equate the marginal value product of labor to its going opportunity cost. This seems to be a good demonstration of short-run disequilibrium being successfully overcome by the rational producer behavior. Producers do indeed seem to react energetically to the existence of disequilibria.

Estimates for the Cobb-Douglas production function elasticities for various inputs are derived indirectly from the profit function estimates for Model III (Table 6.6) using four-year data, and are presented in Table 6.8. These estimates are obtained from identities in Equations 2.30 or 2.34 which are the connecting links between the coefficients of the profit function and those of the production function. The estimates are quite similar to those obtained from Model I presented in Table 5.9 of Chapter V. The main advantage of these indirect input elasticities over the ones obtained from direct-estimates of the production function is their statistical consistency. Since β_1 appears in both the profit and labor demand equations, imposing the restriction

TABLE 6.8

ESTIMATES OF THE INPUT ELASTICITIES OF THE COBB-DOUGLAS PRODUCTION FUNCTION DERIVED FROM THE PROFIT FUNCTION FOR NEW WHEAT 1967/68-1970/71,* PUNJAB, INDIA.

		Model III		
		1 Restriction $\beta_1^L = \beta_1^S$	2 Restrictions $\beta_1^L = \beta_1$ $\beta_1^S = \beta_1$	3 Restrictions $\beta_1^L = \beta_1$ $\beta_2 + \beta_3 = 1$ $\beta^S = \beta_1$
Labor	α_1	0.078	0.218	0.213
Land	α_2	0.636	0.547	0.522
Capital (K)	α_3	0.349	0.280	0.265
$(\alpha_1 + \alpha_2 + \alpha_3)$		1.063	1.045	1.000

*Table 6.2.

that it be equal in both equations improves the efficiency of these estimates. Furthermore, since these estimates are derived from four-year data they should be quite reliable for predictive purposes.

Next we provide two brief comparisons of our results with the researches of Lau and Yotopoulos (March 1971 and Memo 104) regarding relative efficiency in Indian agriculture.

First we note that all our estimates of output elasticities with respect to various inputs (including capital) have the expected signs and reasonable magnitudes. We seem to have been fortunate in having data which yielded reasonable elasticity estimates for capital.[1/]

Secondly, whereas our findings agree with theirs regarding equal relative price efficiency and equal absolute price-efficiency of small and large farms, our findings regarding equal technical and thus equal over-all economic efficiency are not the same. They find small farms relatively more efficient technically and thus more efficient economically, whereas our results indicate no differences in technical or economic efficiency of small and large farms. A possible explanation for this discrepancy might be as follows:

Their findings pertain to the mid-fifties. Indian agriculture at that time could be characterized as traditional and in a state of equilibrium (Schultz, 1964). Modern inputs like chemical fertilizers were conspicuous by their absence. Smaller farms which had more labor

---

[1/] Lau and Yotopoulas obtained (because of the problem of measuring the capital input) negative elasticity for capital and, under constrained estimation with constant returns to scale, relatively large elasticity values for labor and land.

available per unit of land[1] perhaps used it for more intensive land improvement programs which resulted in superior technical efficiency compared to the larger farms. Also as emphasized by Lau and Yotopoulos, under these circumstances, the technical-managerial input becomes more intensive on smaller farms. Their finding of superior technical efficiency of smaller farms thus seems to be consistent with these observations.

Since the mid-fifties, however, Indian agriculture has undergone a great transformation, especially so in Punjab where present-day agriculture can be characterized as modern. The level of land fertility which during mid-fifties perhaps depended on the level of labor input and could be higher on small labor-surplus farms no longer depends upon intensive labor input. The availability of fertilizers, other chemical inputs and increased irrigation input reduces the fertility (productivity) differences of land on small and large farms. Thus a major source of superior technical efficiency of smaller farms during the mid-fifties seems to be absent during the late sixties.

Another explanation can be advanced in the form of an hypothesis. There are two elements to this hypothesis. First, we may agree (in a somewhat qualified manner) with the findings of Lau and Yotopoulos[2] that, in traditional agriculture or in an agriculture in a state of

---

[1] At this point a reference is made again to the studies cited at page 23, particularly by Sen (October 1966), the survey article by Bhagwati and Chakravarty (September 1969), and by Bardhan (1972).

[2] (March 1971).

equilibrium, smaller labor-surplus farms have greater technical efficiency and thereby are more efficient economically. Second, we postulate that large farms have better access to research information because of relatively easier (often free) access to extension services. The period covered by the present study immediately followed the introduction of high-yielding varieties of wheat. Thus, it may well be that larger farms, because of their comparative advantage in research information continued to assimilate the new wheat technology more rapidly than smaller farms and this offset the technical superiority of smaller farms. This hypothesis can be verified only in the future.

Summary

The results and analyses presented in this Chapter show that:

(1) The production function for new wheat is identical on small and large wheat farms and that there are no neutral or non-neutral differences in their production functions.

(2) There are no differences in the technical, price and over-all economic efficiency of small and large wheat farms. The first part of this conclusion actually could be anticipated from (1) above.

(3) Constant returns to scale prevail in the production of new wheat.

The implication of results (1), (2) and (3) is that one cannot argue in favor of large farms on the grounds of economic efficiency.

(4) The first three years of the period studied were characterized by a disequilibrium in wheat farming in the sense that wheat producers did not succeed in equating the marginal value product of

labor to its opportunity cost because of the shifts in labor demand function resulting from the introduction of high-yielding wheats; and that finally during the fourth year this disequilibrium disappeared.

CHAPTER VII

EMPIRICAL RESULTS AND THEIR INTERPRETATION: TRACTOR *VERSUS* NON-TRACTOR FARMS

Comparative analysis of mechanized *versus* non-mechanized farming is a complex problem and is not the point on which this study concentrates. Our aim is limited to a comparison of the economic performance of tractor-mechanized wheat farms with the performance of those without tractors. It has been suggested[1] that in order to exploit the full possibilities for multiple cropping made possible by the use of high-yielding varieties, tractorization in Punjab is necessary to overcome the constraints of labor and annimal power shortages during the months of October-November and April, the two periods of peak farming activity. Sometimes it is also argued that tractorization with multiple cropping results in the use of more labor altogether.[2]

Unfortunately, the research being reported here deals only with the wheat crop, not the full set of farm enterprises on Punjab farms. We are thus unable to account completely for the effects of tractorization on multiple cropping and the resulting use of labor. Since, however, wheat is the most important crop in Punjab and the spurt in

---

[1] See M. H. Billings and A. Singh (1969).

[2] See, for instance, S. S. Johl (1971).

demand for tractors in Punjab occurred after the introduction of high-yielding varieties of wheat, analysis of the comparative efficiency of wheat production with and without tractors would throw some light on the principal issues involved.

The "tractor cultivation sample, 1969/70" forms the data base for our analysis. Out of a total of 287 farms in this sample, 105 farmers owned tractors. We split this sample into tractor-operated farms, 105, and non-tractor operated farms, 182. Sequentially, the analysis proceeds by presenting some basic statistical information and a brief discussion of the two groups of farms. Then we use our basic production function Model 2.2 to examine the question whether tractor and non-tractor farms have the same wheat production function. This is followed by a comparison of the two groups of farms in terms of their economic efficiency, technical efficiency, and price (or allocative efficiency) by using the profit function (Model II: Equations 2.46 and 2.48) in which the dummy variables for large and small farms are replaced by dummy variables for tractor and non-tractor farms with the other variables unchanged. The modified equations are shown in footnotes for Table 7.1. And lastly we compare the estimates obtained from cost functions--Model 2.10--for the two groups of farms.

In Table 7.1, some important per-acre statistics of tractor and non-tractor farms are compared at mean levels of the respective samples. There is hardly any difference in the per acre output of the two types of farms. If anything, average wheat yield per acre is slightly higher--on the order of 0.9 percent--on non-tractor farms, contrary

TABLE 7.1

PER ACRE INPUT USE AND SOME OTHER STATISTICS AT SAMPLE MEANS, NEW WHEAT, 1969/70, PUNJAB, INDIA

	Tractor Farms	Non-tractor Farms	All Farms
Average wheat area (acres)	24.78	11.38	16.29
Output (quintals)	9.13	9.21	9.16
Labor (hours)	159.84	208.41	181.21
Labor bill (rupees)	121.87	159.28	138.43
Capital, K_1 (rupees)	183.78	90.86	142.54
Animal power (hours)	17.12	97.78	52.84
Animal power, B (rupees)	20.04	93.62	52.61
Fertilizer costs, F (rupees)	63.56	55.98	60.16
Capital, K_2 (rupees)	203.83	184.48	195.15
Capital K (rupees)	267.39	240.46	255.31
Land rent, t (rupees)	209.56	220.26	214.06
Wage rate, w (rupees)	0.76	0.76	0.76
Total costs (rupees)	598.50	620.02	607.80
Cost per quintal (rupees)	65.66	67.32	66.35

Notes: Capital (K) = the total capital flow including physical capital (K_1), animal power (B) and fertilizer costs (F).
Capital (K_2) = flows from the physical capital(K_1) plus animal power (B).
Capital (K_1) = flow of physical capital. $K_1 = K - B - F$.

to the view that tractor mechanization is necessary for increasing land productivity.[1/] With regard to the use of different inputs per acre we find that the average non-tractor farm used about 30.5 percent more labor, 367 percent more animal power, 50.6 percent less physical capital (K_1), 11.9 percent less fertilizer, and incurred 5.3 percent more rental costs, t, for land. Average wage rate for labor is exactly the same for both types of farms and unit costs of production of wheat are hardly any different. In Table 7.2, input-output coefficients at respective sample means are provided, which is only a different way of presenting the information of Table 7.1. The conclusions that we draw from these two tables are rather obvious. Whereas we find no evidence of any significant differences in land productivity and unit costs of producing wheat between the two groups of farms, the input composition is considerably different. Farms with tractors use more than 100 percent more capital (K_1) per acre compared to farms without tractors. This they use not only to replace animal power, which of course is curtailed tremendously, but human labor as well. The labor displacement effect of tractor mechanization on the order of about 25 percent per acre is clear from these tables.

Production Function Model

The statistical information presented above is quite useful in the sense that it allows us to discuss broad differences among the two

---

[1/] See G. W. Giles (1967), B. S. Patkak (1970), S. S. Johl (1971) and Roger Lawrence (1970), among others, for this view.

TABLE 7.2

INPUT-OUTPUT COEFFICIENTS PER QUINTAL OF WHEAT, AT SAMPLE MEANS, NEW WHEAT, 1969/70, PUNJAB, INDIA

	Tractor Farms	Non-tractor Farms	All Farms
Labor (hours)	17.49	22.62	19.78
Labor bill (rupees)	13.35 (0.204)	17.29 (0.257)	15.11 (0.227)
Land (acres)	0.11	0.11	0.11
Land rent (rupees)	22.92 (0.350)	23.91 (0.356)	23.37 (0.353)
Capital (K_1) (rupees)	20.22 (0.307)	9.86 (0.147)	15.56 (0.235)
Animal power (hours)	1.87	10.61	5.77
Animal power (rupees)	2.19 (0.033)	10.16 (0.150)	5.74 (0.086)
Fertilizer (rupees)	6.96 (0.106)	6.08 (0.090)	6.57 (0.099)
Capital (K_2) (rupees)	22.41 (0.340)	20.02 (0.297)	21.30 (0.321)
Capital (K) (rupees)	29.28 (0.446)	26.10 (0.387)	27.87 (0.420)
Cost (rupees)	65.55 (1.000)	67.32 (1.000)	66.35 (1.000)

Notes: For definition of variables see Table 7.1.

The figures in parentheses are the expenditure shares of the respective inputs in per quintal costs of wheat.

types of farms. There are, however, more important issues in any economic efficiency comparison of tractor and non-tractor farms, and these issues require the use of a more refined approach. Moreover, the concept of economic efficiency is quite elusive and this further necessitates the use of advanced techniques to study the problem. The profit function formulation--Model II--is an appropriate tool for this purpose; by using the profit function, we can compare economic efficiency and its components of technical and price efficiency for the two groups of farms. This is essentially what we do in the next section. This approach, however, assumes that there are no non-neutral differences in the production functions of the two groups of farms. Put differently we assume that the two production functions have only neutral differences in the sense that the efficiency parameters of the Cobb-Douglas production functions vary but not the output elasticities with respect to the different inputs. In this section we wish to test this assumption for tractor and non-tractor farms by comparing their separate production function estimates of Model 2.2 with those from the pooled data. Additionally we also examine the question of returns to scale.

Table 7.3 provides the results of least squares regressions for separate tractor and non-tractor functions as well as functions with pooled data with and without a dummy variable for tractor farms. First, we perform analysis of covariance tests comparing separate regressions I and II with the over-all regression VII and separate regressions IV and V with over-all regression VIII. These comparisons are for testing the hypothesis that separate regressions belong to the same

TABLE 7.3

ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1969/70, TRACTOR AND NON-TRACTOR FARMS, PUNJAB, INDIA

Regression Number	Type of Farm	No. of Obser-vations	Constant	Coefficient of D^T	Labor	Land	Capital (K_2 or K)	Ferti-lizer	R^2	SEE[a]	Returns to Scale	F-ratio*
I	Tractor	105	-0.188 (0.674)		0.339 (0.105)	0.412 (0.123)	0.242 (0.095)	0.013 (0.046)	0.772	0.318	1.006	0.01
II	Non-tractor	182	1.528 (0.354)		0.047 (0.075)	0.829 (0.073)	0.080 (0.068)	0.032 (0.020)	0.870	0.323	0.988	0.18
III	All	287	1.092 (0.311)	0.023 (0.050)	0.122 (0.061)	0.718 (0.063)	0.118 (0.055)	0.030 (0.018)	0.877	0.325	0.988	0.14
IV	Tractor	105	-0.252 (0.721)		0.351 (0.105)	0.398 (0.124)	0.249 (0.103)		0.772	0.318	0.998	0.003
V	Non-tractor	182	1.082 (0.383)		-0.005 (0.072)	0.790 (0.073)	0.208 (0.070)		0.873	0.318	1.004	0.01
VI	All	287	0.772 (0.337)	0.011 (0.049)	0.100 (0.059)	0.690 (0.064)	0.202 (0.057)		0.879	0.322	0.992	0.06
VII	All	287	1.064 (0.305)		0.113 (0.052)	0.723 (0.305)	0.127 (0.051)	0.030 (0.018)	0.877	0.325	0.993	0.09
VIII	All	287	0.758 (0.330)		0.096 (0.056)	0.692 (0.063)	0.206 (0.054)		0.879	0.321	0.994	0.06

Notes: Equations linear in logarithms are estimated by least squares.
Dependent variable is output of wheat in physical units.
Standard errors of coefficients are in parentheses.

*Calculated F-ratios are for testing the hypothesis of constant returns to scale.

D^T is the dummy variable with value of one for tractor operated farms and zero for non-tractor operated farms.

[a]/Standard errors of estimate are in natural logarithms of wheat output measured in quintals.

R^2 is the coefficient of determination adjusted for degrees of freedom.

production structure that is, the sets of coefficients in the separate regressions are equal. The respective F-ratios are 2.08 with 5 and 277 degrees of freedom and 2.37 with 4 and 279 degrees of freedom. Both these F-ratios are significant at 90 percent level (but not at 95 percent). That is, we reject, at the 90 percent level of significance, the hypothesis that the two separate regressions belong to the same production structure. Secondly, we allow the intercepts for the separate regressions to vary by introducing an intercept dummy for the tractor farms and compare separate regressions I and II with over-all regression III and separate regressions IV and V with over-all regression VI. We note that the coefficients for the dummy variable in either of the over-all regressions III and IV are not significantly different from zero. The respective analysis of covariance F-ratios are 2.54 with 4 and 277 degrees of freedom and 3.15 with 3 and 279 degrees of freedom. Again both F-ratios are significant at 95 percent level (but not 99 percent). On the basis of these tests we reject the hypothesis of equality between sets of coefficients in the separate regressions, though not very strongly. Hence we cannot say with complete confidence that there are no non-neutral differences in wheat production technology with and without tractors.

An alternative approach to sort out the differences between the regression coefficients of tractor and non-tractor forms could be followed by introducing directly in the pooled data slope-shifting variables for tractor farms. Least-squares estimates of such a regression are presented in Table 7.4. Only the (negative) coefficient

Slope Dummy

TABLE 7.4

ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, TRACTOR AND NON-TRACTOR FARMS, WITH SLOPE DUMMIES, 1969/70, PUNJAB, INDIA

	Regression Coefficients	
Constant	1.164	(0.315)
Labor	0.068	(0.075)
Labor (D^T)	0.185	(0.122)
Land	0.771	(0.068)
Land (D^T)	-0.179*	(0.097)
Capital, K_2	0.129	(0.065)
Capital, K_2 (D^T)	-0.034	(0.079)
Fertilizer	0.035	(0.020)
Fertilizer (D^T)	-0.042	(0.050)
R^2	0.878	
SEE[a]	0.323	

Notes: Equations linear in logarithmic are estimated by least squares.
Dependent variable is output of wheat in physical units.
Labor (D^T), Land (D^T), Capital (D^T) and Fertilizer (D^T) are the slope-shifting variables for tractor farms. They are obtained by multiplying the logarithmic transform of the original variables of labor, land, capital K_2 and fertilizer by D^T a zero-one variable with a value of one for tractor farms and zero for non-tractor farms.
Standard errors of coefficients are in parentheses.
*Significant at 90 percent level using two-tailed t test.
a/Standard error of estimate is in natural logarithms of wheat output measured in quintals.
R^2 is the coefficient of determination adjusted for degrees of freedom.

for slope-shifting variable for land is significantly different from zero at 90 percent level using two-tailed t test whereas the coefficients for all other slope-shifting variables are not significant. Even for land this may not be considered as conclusive evidence that tractor and non-tractor farms have different coefficients for land. There are reasons to believe that the land variable measured in acres has quality differences and may not represent a homogeneous input. Partly the quality adjustments are taken account of if we use a value measure of land, that is, land rent instead of land acres. We do this in a subsequent section.

A careful examination of the results presented in Table 7.3 makes us suspect the quality of these results. Coefficients for labor and land appear to have implausible values in the sense that labor coefficients in some cases are not even significant and land coefficients seem to be unduly large. It seems that because of the high intercorrelations[1/] among the independent variables the coefficient of land usurps the coefficient of labor. In order to verify this hypothesis, expenditure shares of each factor of production in total costs as well as total revenue are calculated at the geometric means of the respective samples. The results of these computations are shown in Table 7.5. A comparison of the calculated factor shares with the corresponding input elasticity estimates of Table 7.3 confirms our suspicion.[2/] Whereas

---

[1/] Zero order correlations are presented in Appendix Table III.1.

[2/] In making this comparison I do not wish to imply that the factor shares are ideal estimates with which to compare our estimates. In fact I am quite aware of the difficulties involved in their interpretation as coefficients of the production function. The only purpose for which we make this comparison is to highlight the suspect quality of our production function estimates.

the calculated factor share (Table 7.5) of labor is larger for non-tractor farms relative to the tractor farms, the estimated coefficients for non-tractor farms (Table 7.3) are not significant. Probably high intercorrelations among the independent variables as suggested above are responsible for these results. The coefficient for land seems to have usurped the influence of both labor and capital in the case of regression II and that of labor in the case of regression V. A part of the problem, as argued before, could be in the measurement of land services because of quality differences.

From Table 7.1 we find that relative to tractor farms, non-tractor farms on an average incur a little over 5 percent more per acre rental costs for land which implies they may have better land. To account for possible quality differences in the land variable, we run least squares regressions using value measures for all inputs, for tractor and non-tractor farms, as well as with the pooled data with and without a dummy variable for tractor farms. The results of these regressions are presented in Table 7.6. It turns out that the estimates--relative to those of Table 7.3--improve considerably both in terms of the standard errors as well as the magnitudes of the estimates. Furthermore statistical tests comparing production functions for tractor and non-tractor farms, show that both types of farms belong to the same production structure. These tests are as follows:

(1) F-ratios comparing separate regressions I and II with over-all regression III, and separate regressions V and VI with over-all regression VII are 0.67 with 5 and 277 degrees of freedom and 0.67 with 4 and 279 degrees of freedom respectively. Neither of these

TABLE 7.5

EXPENDITURE SHARES AT SAMPLE GEOMETRIC MEANS, NEW WHEAT, 1969/70, PUNJAB, INDIA

		Tractor Farms		
		Geometric Mean	Share in Total Costs	Share in Total Revenue
Output	(quintals)	184.93		
Output*	(quintals)	226.24		
Total costs	(rupees)	12838.40		
Total revenue	(rupees)	14189.00		
Labor bill	(rupees)	2540.68	0.198	0.179
Land rent	(rupees)	4230.20	0.329	0.298
Capital (K_1)	(rupees)	3827.60	0.298	0.269
Animal power	(rupees)	175.91	0.013	0.012
Fertilizer costs	(rupees)	1096.60	0.085	0.077
Capital (K_2)	(rupees)	4360.34	0.339	0.307
Capital (K)	(rupees)	5760.10	0.448	0.405
		Non-tractor Farms		
		Geometric Mean	Share in Total Costs	Share in Total Revenue
Output	(quintals)	75.19		
Output*	(quintals)	104.83		
Total costs	(rupees)	5378.70		
Total revenue	(rupees)	5710.10		
Labor bill	(rupees)	1339.40	0.249	0.234
Land rent	(rupees)	1808.00	0.336	0.316
Capital (K_1)	(rupees)	721.10	0.134	0.126
Animal power	(rupees)	706.24	0.131	0.123
Fertilizer costs	(rupees)	347.23	0.064	0.060
Capital (K_2)	(rupees)	1572.20	0.292	0.275
Capital (K)	(rupees)	2038.80	0.379	0.379
		All Farms		
		Geometric Mean	Share in Total Costs	Share in Total Revenue
Output	(quintals)	104.58		
Output*	(quintals)	149.25		
Total costs	(rupees)	7427.18		
Total revenue	(rupees)	7925.02		
Labor bill	(rupees)	1686.34	0.227	0.212
Land rent	(rupees)	2465.70	0.331	0.311
Capital (K_1)	(rupees)	1313.40	0.176	0.165
Animal power	(rupees)	424.11	0.057	0.053
Fertilizer costs	(rupees)	528.61	0.071	0.066
Capital (K_2)	(rupees)	2276.28	0.306	0.287
Capital (K)	(rupees)	2981.00	0.401	0.376

Note: *Sample arithmetic mean.

TABLE 7.6

ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1969/70, TRACTOR AND NON-TRACTOR FARMS, PUNJAB, INDIA

Regression Number	Type of Farm	No. of Observations	Constant	Coefficient of D^T	Labor	Land	Capital (K_2 or K)	Fertilizer	R^2	SEE[a]	Returns to Scale	F-ratio*
I	Tractor	105	-3.101 (0.446)		0.255 (0.083)	0.482 (0.082)	0.243 (0.087)	0.038 (0.043)	0.790	0.305	1.002	0.11
II	Non-tractor	182	-2.948 (0.231)		0.164 (0.063)	0.625 (0.061)	0.149 (0.065)	0.051 (0.021)	0.857	0.338	0.989	0.53
III	All	287	-3.057 (0.181)		0.179 (0.048)	0.583 (0.049)	0.194 (0.048)	0.052 (0.018)	0.876	0.325	1.010	0.70
IV	All	287	-2.980 (0.197)	0.048 (0.049)	0.190 (0.049)	0.580 (0.049)	0.175 (0.051)	0.050 (0.018)	0.876	0.325	0.995	0.00
V	Tractor	105	-3.160 (0.447)		0.270 (0.081)	0.478 (0.084)	0.263 (0.090)		0.790	0.305	1.010	0.04
VI	Non-tractor	182	-3.157 (0.227)		0.120 (0.061)	0.581 (0.062)	0.296 (0.065)		0.863	0.331	0.997	0.01
VII	All	287	-3.235 (0.176)		0.161 (0.047)	0.551 (0.049)	0.298 (0.048)		0.879	0.321	1.010	0.18
VIII	All	287	-3.173 (0.195)	0.036 (0.048)	0.168 (0.049)	0.550 (0.050)	0.283 (0.052)		0.879	0.322	1.000	0.00

Notes: Equations linear in logarithms are estimated by least squares.
Dependent variable is output of wheat in physical units. Independent variables are measured in value terms.
D^T is a dummy variable with a value of one for tractor farms and zero for non-tractor farms.
Standard errors of coefficients are in parentheses.

*F-ratios are calculated for testing the hypothesis of constant returns to scale.

a/Standard errors of estimate are in natural logarithms of wheat output measured in quintals.

R^2 is the coefficient of determination adjusted for degrees of freedom.

F-ratios is significant at the 90 percent level. We thus can not reject the hypothesis of the equality between sets of production coefficients in tractor and non-tractor production functions.

(2) Over-all regressions IV and VIII are run to allow the intercepts of tractor and non-tractor farms to vary by introducing an intercept dummy for tractor farms. In both cases we find that the coefficients for the dummy variable are not significantly different from zero. The F-ratios comparing separate regressions I and II with over-all regression IV, and separate regressions V and VI with over-all regression VIII are 0.56 with 4 and 277 degrees of freedom and 0.13 with 3 and 279 degrees of freedom. Again none of these F-ratios is significant at the 90 percent level. This further supports the hypothesis of equality between sets of production coefficients in the tractor and non-tractor production functions.

Before we go further to compare the over-all economic performance of tractor and non-tractor farms using the profit function model, we may note--in Tables 7.3 and 7.6--that there is no evidence against the hypothesis of constant returns to scale in the range of observations in either tractor or non-tractor farms. We may also repeat that the estimated coefficients in Table 7.6 using value measures for inputs, are better estimates in the sense that they have larger t ratioes than those for the estimated coefficients of Table 7.3 where land and labor are measured in physical units. This is perhaps because part of the quality adjustments for inputs are taken care of by the value measure.

Profit-Function Model

Here our main objective is to compare the over-all economic efficiency of tractor-operated and non-tractor-operated farms. We will verify our earlier finding from the production function model that there exist no differences in the technical efficiency of tractor and non-tractor farms and also compare the price (or allocative) efficiency of these two types of farms with respect to labor use. Knowledge of the differences in the parameters of technical and price efficiency of tractor and non-tractor farms could have important implications for policy purposes. If for example we find that tractor farms are more price-efficient and if the society wishes to improve the comparative position of the smaller non-tractor farms, policies to subsidize the variable input in question, and the provision of better (and cheaper) agricultural education and extension services for the smaller non-tractor farms would be the relevant measures to consider. We will comment later on various policy issues in the light of our findings--(see pages 153 to 156).

For analyzing relative economic efficiency of the two groups of farms, we use the profit function (Model II: Equations 2.46 and 2.48) after replacing the dummy variables for large and small farms with tractor and non-tractor farms. The equations and the results of their joint estimation using Zellner's method (1962) with restrictions are shown in Table 7.7, along with the results from single-equation ordinary least squares.

TABLE 7.7

RESULTS OF JOINT ESTIMATION OF COBB-DOUGLAS PROFIT FUNCTION AND LABOR DEMAND FUNCTION FOR NEW WHEAT, 1969/70, PUNJAB, INDIA

		Estimated Coefficients				
			Zellner's Method with Restrictions (Model II)			
Function	Parameter	Single Equation Ordinary Least Squares	Unrestricted	1 Restriction	2 Restrictions	3 Restrictions
				$\beta_1^T = \beta_1^{NT}$	$\beta_1^T = \beta_1$ $\beta_1^{NT} = \beta_1$	$\beta_1^T = \beta_1$ $\beta_2 + \beta_3 = 1$ $\beta_1^{NT} = \beta_1$
UOP Profit Function	λ	4.830 (0.501)	4.778 (0.433)	4.794 (0.433)	4.811 (0.441)	4.934 (0.398)
	δ^T	0.089 (0.073)	0.075 (0.070)	0.032 (0.063)	0.041 (0.064)	0.062 (0.054)
	β_1	-0.286 (0.124)	-0.062 (0.107)	-0.064 (0.107)	-0.253 (0.081)	-0.256 (0.081)
	β_2	0.790 (0.083)	0.785 (0.071)	0.785 (0.071)	0.788 (0.073)	0.779 (0.072)
	β_3	0.224 (0.085)	0.241 (0.073)	0.241 (0.073)	0.235 (0.075)	0.221 (0.072)
Labor Demand Function	β_1^T	-0.259 (0.203)	-0.259 (0.202)	-0.481 (0.122)	-0.252 (0.081)	-0.256 (0.081)
	β_1^{NT}	-0.610 (0.153)	-0.610 (0.153)	-0.481 (0.122)	-0.252 (0.081)	-0.256 (0.081)
	R^2	0.777				

See notes on following page.

TABLE 7.7 (continued)

Notes: The estimating equations are:

$$\ln \pi = \lambda + \delta^T D^T + \beta_1 \ln w + \beta_2 \ln L + \beta_3 \ln K$$

$$-\frac{wN}{\pi} = \beta_1^T D^T + \beta_1^{NT} D^{NT}$$

where

D^T is a dummy variable taking the value of one for farms owning a tractor and zero otherwise.

D^{NT} is a dummy variable taking the value of one for farms not owning a tractor (animal operated) and zero otherwise.

Asymptotic standard errors are in parentheses.

In order to compare the efficiency of tractor and non-tractor farms, we carry out the following statistical tests:

(1) The hypothesis of equal relative economic efficiency of tractor and non-tractor farms:

$$Ho: \delta^T = 0,$$

that is, $\ln (A_*^T/A_*^{NT}) = 0$, or $A_*^T = A_*^{NT}$.

$F(1,567) = 1.13 < F_{(0.10)}(1,567) = 2.70$, and the null hypothesis is not rejected. We conclude that tractor and non-tractor farms have equal economic efficiency.

(2) The hypothesis of equal relative price efficiency of tractor and non-tractor farms:

$$Ho: \beta_1^T = \beta_1^{NT}$$

The meaning of this test is whether tractor and non-tractor farms have the same price efficiency parameters β_1^T and β_1^{NT} in their labor demand functions.

$F(1,567) = 1.92 < F_{(0.10)}(1,567) = 2.70$, and the null hypothesis cannot be rejected. Hence we conclude that both tractor and non-tractor farms are equally price-efficient, i.e., they have the same price efficiency parameters (k^i's).

(3) The joint hypothesis of equal relative technical <u>and</u> price efficiency of tractor and non-tractor farms:

$$Ho: \ \delta^T = 0$$

and

$$\beta_1^T = \beta_1^{NT}$$

The meaning of these tests is whether tractor and non-tractor farms have equal economic efficiency and whether at the same time have the same price efficiency parameter in their labor demand functions.

$F(2,567) = 1.09 < F_{(0.10)}(2,567) = 2.30$, and again we cannot reject the null hypothesis. This actually confirms the conclusions in (1) and (2) above that tractor and non-tractor farms have equal economic efficiency and equal price efficiency and in turn implies that they have equal technical efficiency.

(4) Next maintaining the hypothesis of equal price efficiency in (2), we turn to the hypotheses of:

(a) Absolute price efficiency of tractor farms,

$$Ho: \ \beta_1^T = \beta_1, \text{ and}$$

(b) Absolute price efficiency of non-tractor farms,

$$Ho: \ \beta_1^{NT} = \beta_1.$$

The meaning of these tests is whether tractor and non-tractor farms maximize profits by equating the value of marginal product of labor to its opportunity price.

$F(4,567) = 4.31 > F_{(0.05)}(2,567) = 3.00$, and the null hypothesis is rejected. The conclusion is that both tractor and non-tractor farms were not able to maximize profits successfully during the year 1969/70. In light of the results of test for the hypothesis of equal relative price efficiency in (2), we conclude that, with respect to labor, tractor and non-tractor farms have been equally unsuccessful in their efforts to maximize profits by using the optimum amount of labor.

(5) The hypothesis of constant returns to scale.

$$Ho: \beta_2 + \beta_3 = 1.$$

$F(1,567) = 914.14 > F_{(0.10)}(1,567) = 2.70$, and the null hypothesis is rejected. We, however, observe that the actual sum of β_2 and β_3 is only slightly different from one. Thus even though on statistical grounds we reject the hypothesis of constant returns to scale, we find evidence is not strong enough to favor the hypothesis of decreasing returns to scale.

The results of the above statistical tests have important implications with respect to tractor mechanization policies for Indian agriculture. But before proceeding with that discussion, we wish to re-examine, in the next section, with help from the results obtained for the cost function Model 2.10, our earlier argument that larger producers obtain indirect subsidies in the form of lower capital prices. This will make possible a more integrated discussion of the policy implications of our findings.

Cost Function Model

The results from the least squares regression estimates for the cost function Model 2.10 presented in Table 7.8 differ from earlier findings in this chapter on two major points. First, contrary to the earlier finding of constant returns to scale, increasing returns are indicated. Second, we find that the coefficient for the intercept-shifting dummy variable for tractor farms in regression IV has a positive sign and is significantly different from zero at 99 percent level using two-tailed t test. The test comparing tractor and non-tractor regressions I and II with regression IV, indicates that there are no differences in the sets of regression coefficients of the two equations other than in the constant term.[1/] This means that the estimated long-run average cost function for tractor farms lies above that of the non-tractor farms. The questions that we seek to answer here are what causes increasing returns to scale in the cost function model and what causes the long-run average cost function for tractor farms to be above that of the non-tractor farms.

By way of explanation of these phenomena we summarize a few of the earlier findings and arguments:

(1) From the production function estimates, we found consistent evidence of constant returns to scale for tractor and non-tractor farms

---

[1/] The analysis of covariance F-ratio for this test is equal to 1.59. With 3 and 279 degrees of freedom this F-ratio is not significant at 90 percent level. We thus cannot reject the hypothesis of equality between the sets of regression coefficients of the two equations while allowing the intercept terms to differ.

TABLE 7.8

ESTIMATES OF COST FUNCTION FOR NEW WHEAT, TRACTOR AND NON-TRACTOR FARMS, 1969/70, PUNJAB, INDIA

Regression Number	Type of Farm	No. of Obser-vations	Constant	Coefficient of D^T	Coefficient of Y	Coefficient of w	Coefficient of t	R^2	SEE[a]	Returns to Scale
I	Tractor	105	4.722 (0.449)		0.764 (0.039)	0.223 (0.110)	0.065 (0.075)	0.783	0.268	1.308*
II	Non-tractor	182	3.963 (0.408)		0.845 (0.025)	0.056 (0.097)	0.164 (0.069)	0.856	0.310	1.184*
III	Over-all	287	4.103 (0.305)		0.856 (0.019)	0.127 (0.074)	0.111 (0.051)	0.874	0.301	1.168*
IV	Over-all	287	4.159 (0.301)	0.127 (0.041)	0.825 (0.021)	0.118 (0.073)	0.122 (0.050)	0.878	0.297	1.212*

Notes: Equations linear in logarithms are estimated by least squares.

Dependent variable is total cost in rupees.

D^T is a dummy variable with a value of one for tractor farms and zero for non-tractor farms.

a/ Standard errors of estimate are in natural logarithms of total cost, measured in rupees.

*Indicates returns to scale are significantly different from one at 99 percent level.

Standard errors of coefficients are in parentheses.

as well as for the pooled data. Also from the profit function model we found no evidence against constant returns to scale.

(2) By computations based on estimates of regression Equation IV, Table 7.8, at the respective sample mean levels of output (for non-tractor farms = 104.83 quintals; for tractor farms = 226.24 quintals) and using the geometric mean wage rate and land rent, we obtain average cost of rupees 67.21 per quintal for non-tractor farms and rupees 66.60 per quintal for tractor farms. These average costs per quintal are approximately the same as we obtained earlier from arithmetic calculations[1/], that is, rupees 67.32 per quintal for non-tractor farms and rupees 65.55 per quintal for tractor farms.

(3) The inference from (1) and (2) is that for the sample as a whole the long-run average cost curve is a straight line at about rupees 66.44 per quintal.

(4) Then, the explanation for increasing returns to scale obtained from the cost function model could be our earlier argument (page 58) that the omission of capital price from our estimating Equation 2.10 biases the coefficient $\frac{1}{\gamma}$ for logarithm of output downward and in turn γ, the measure of returns to scale upward. It seems worthwhile to repeat this argument.

A complete specification of the cost function model is Equation 2.9. The lack of data on capital price "i" reduced our estimating model to 2.10 which we estimate without "i". We have argued on

---

[1/] See Table 7.1.

a priori considerations that the real price of capital is lower for larger producers[1] relative to the smaller ones. This implies a negative relationship between the omitted variable, logarithm of capital price "i" and logarithm of output Y. This, as is well known,[2] biases downward the coefficient $\frac{1}{\gamma}$ for logarithm of Y and thus we get an upward bias in γ, the measure of returns to scale. It is important to note here that this bias seems to be somewhat more pronounced in the case of tractor farms. This seems to lend additional weight to our argument. The negative relationship between logarithm of ourput and omitted capital price may be stronger in case of tractor farms than non-tractor farms, that is, more capital-intensive tractor farms producing larger output could be enjoying still lower real prices for capital compared to less capital-intensive and relatively smaller farms.

(5) It seems more difficult to explain why the long-run average cost curve for tractor-farms should be above that of the non-tractor-farms as indicated by a positive and significant coefficient for the intercept-shifting dummy variable for tractor-farms. It could possibly be due to two reasons. First, we noted above that the unit costs of production at respective mean levels of output of non-tractor and tractor farms are almost equal. This implies that tractor farms with smaller than mean output level (226.24 quintals) of all tractor-farms, should have larger unit cost than the non-tractor farms which have

---

[1] See Chapter I, page 6, for reasons for this.

[2] See Griliches (1957).

larger than the mean output level (104.83 quintals) of all non-tractor farms. This could happen if the smaller tractor farms are not able to spread the fixed costs of machinery over large enough levels of output. In this situation tractor farms could have a larger intercept term which would show up as a positive coefficient for the dummy variable for tractor farms. Second, if we accept the arguments that omission of capital price from the cost function model may have biased downward the coefficient of logarithm of output more in case of tractor farms than non-tractor ones, this could enlarge the intercept term for tractor-farms relative to non-tractor farms. This in turn would show up as a positive coefficient for the dummy variable for tractor farms in the pooled regression.

Summary and Policy Implications

The major findings of this chapter are:

(1) There are no differences in the land productivity of tractor and non-tractor operated farms in the production of wheat.

(2) There is also no difference in the unit costs of producing wheat at the respective mean output levels of tractor and non-tractor farms.

(3) Non-tractor farms use 367 percent more animal power, about 30 percent more labor, but 50 percent less physical capital per acre, relative to tractor farms.

(4) Both tractor and non-tractor farms have the same wheat production function.

(5) There are no differences in over-all economic efficiency and its components (technical efficiency and price efficiency) between tractor and non-tractor farms in wheat production.

(6) There exist constant returns to scale in wheat farming for both tractor and non-tractor farms.

It is interesting that during a period of rapidly changing agricultural technology, tractor and non-tractor wheat farms were equal in economic performance. If in fact during a period of static agricultural technology, smaller (non-tractor) farms are economically more efficient,[1/] during a period of rapid change, tractor farms may have attained equal economic efficiency due to their better (and earlier) access to agricultural knowledge, cheaper access to capital, or both during this period.

We have not examined the issue that mechanization increases the possibilities for multiple cropping and thus perhaps results in a net increase of labor employment per acre. Tractorization seems to result in reduced labor use on the order of 25 percent per acre (Table 5.1) in wheat production. There seems to be no logical reason why similar results should not be expected in case of rice, corn, sugarcane, cotton or any other crop. Yet it seems possible that tractorization may help in increasing the possibility of multiple cropping, particularly on larger farms. Whether this increase in multiple cropping results in

---

[1/] See Lau and Yotopoulos (1971 and Memo. 104) for this finding.

net increase in labor use per unit of land should be an important question for future inquiry. But as far as wheat is concerned the labor-replacing effect of tractorization is clear.

It seems worth emphasizing that this is not an argument against all types of mechanization or for that matter even tractorization. Certain kinds of selective mechanization, consistent with the agronomic and physical necessities of farming and as induced by the relative factor endowments, may be necessary. On non-tractor-operated farms one finds clear signs of this type of mechanization, which, as a matter of fact, is proceeding fairly rapidly.

The important lesson from these findings, however, is that it will be unfortunate if the increased labor-absorptive capacity of agriculture[1/] opened up as a result of the 'green revolution' is permitted to be dissipated by fast increases in labor-replacing tractor mechanization or other heavy machinery. What could be avoided at the very least (or perhaps must be avoided) is the mechanization that takes place as a result of direct or indirect subsidization. The results of the analysis presented above seem to support the argument that tractor-operated wheat farms may be enabled to achieve the level of economic performance of non-tractor farms through capital subsidies. Considerations of social justice and concern for employment opportunities for the rapidly growing labor force of India make it difficult to defend

---

[1/] It may be helpful to refer back to our findings on this point in Chapter IV, pages 54 and 55.

subsidization policies which help the larger farmers conceal their inefficiency. It is reported that the labor force may increase from 210 million in 1970 to 273 million by the end of the decade.[1/] There is very little hope that the non-agricultural sector can absorb increased labor force of such a high order. Policy measures to discourage (or at least not to encourage) mechanization which causes heavy displacement of labor are necessary if the society is interested in reducing unemployment.

[1/] See Robert d'A. Shaw (1970, p. 2).

CHAPTER VIII

SUMMARY AND CONCLUSIONS

In many countries of Asia, the recent agricultural transformations that are resulting from the spread of high-yielding varieties of wheat and rice have generated new hopes for the economies of these countries. It is important to understand the nature and significance of these changes if one is interested in devising measures for the furtherance and continuation of this process of transformation.

The main purpose of this study was a quantitative assessment of this transformation in the case of wheat during the years 1967/68 to 1970/71, using the Indian Punjab, which is located in the center of the Indo-Pakistan wheat growing region as the base area of study. Put differently we seeked to explain the process of absorption of new wheat technology, that is the process of technical change concomitant with the introduction of new wheat seed. Specifically the major objectives were: (1) to study the nature and magnitude of technical change in wheat production technology resulting from the introduction of high-yielding varieties of wheat, (2) to compare the long-run cost functions of old and new wheats and to obtain estimates of savings in the unit costs of producing wheat resulting from the adoption of new wheat varieties, (3) to compare the economic performance of small *versus* large and tractor-operated *versus* non-tractor-operated wheat farms, (4) to investigate the response of wheat-producers to disturbances in factor markets generated by the shifts in factor productivities resulting from the adoption of new wheat technology, (5) to obtain estimates of several useful elasticity measures, (6) to investigate the role of education in wheat production and (7) to study the existence of economies of scale and then explore implications for wheat production.

For empirical implementation of the objectives listed above three different but interrelated models, based on the theory of production, were used. Questions of differences in the production function of old and new wheats, the productive value of education and returns to scale were analyzed with the help of a simple production model based on the standard neoclassical (Cobb-Douglas) production function. A cost function model essentially developed by Nerlove (1965) was used to compare the differences in the long-run cost functions of old and new wheats and over time, to study returns to scale and more importantly to explore whether the degree of returns to scale varies over the sample range. In order to study relative economic efficiency of small <u>versus</u> large farms and tractor <u>versus</u> non-tractor farms we used profit function models[1/] developed by Lau. These models also enabled us to obtain consistent production function estimates, to derive several other important elasticity estimates, and to study the question of returns to scale. It was both useful and necessary to employ all three models in order to accomplish the objectives set forth for this

---

[1/] See Lau (Memos 86A and 86B, 1969) for the development of these models and Lau and Yotopoulos (1971, 1972 and Memos 104 and 108) for their applications.

research and--in some cases--to compare the results from them. Theoretical development and operational aspects of these models are discussed in Chapter II.

The data, on which the empirical findings are based, came from private farms. Studies in farm management conducted by the Government of India during the years 1967/68 and 1968/69 in the Ferozepur district of Punjab, and a similar study by the Government of Punjab during the year 1969/70 (conducted in 19 villages spread over practically the whole of Punjab) are the major sources of data. These data are supplemented by farm data for the year 1970/71 collected under the author's personal supervision. Sampling procedures and methods of collection of these data, and the definition of the variables used in empirical estimation work are discussed in Chapter III.

Empirical Findings and Conclusions

An essential ingredient of technical change is a shift in the production function such that a larger output is obtained for a given level of inputs or a given level of output can be produced with smaller quantities of inputs. The emphasis is on the shift in the function in the sense of expansion of the production boundaries and should not be confused with movements towards known or existing boundaries.

The estimates of such a production function shift resulting from the 1967/68 introduction of new wheat varieties, and its effects on the cost function and factor demand functions are presented in Chapter IV.

The results indicate that the shift has been of the neutral type implying that the unit isoquant for wheat has shifted downward without any change in its slope, that is, without affecting the marginal rates of substitution between inputs. Direct estimates of the Cobb-Douglas production function indicate that the efficiency parameter for new wheat varieties is larger by 22.85 to 28.04 percent than the efficiency parameter for old wheat. Values of the efficiency parameter derived indirectly from the cost function and from the profit function estimates indicate an efficiency gain on the order of 21.45 percent and 44.70 percent respectively. Being statistically consistent the estimates obtained from profit function model are taken to be superior to the ordinary least squares estimates. Thus the magnitude of gain in efficiency of the technology indicated by the profit function estimates--44.70 percent--should be considered a more reliable estimate. But it is noteworthy that even the lowest estimate of 21.45 percent gain in the efficiency parameter obtained from the cost function estimates is quite spectacular, perhaps the largest reported in the history of improvement of cereal crop technology. In the case of hybrid corn, an outstanding U.S. example of technological success based on seed improvement, a 15 to 20 percent increase in yield of corn was reported[1/] over the open-pollinated varieties. Yield increases for new wheat varieties over old varieties are far more spectacular. Research

---

1/See Griliches (1958).

findings[1] from the Punjab Agricultural University indicate 61.90-63.43 percent yield increase per acre for new wheat over the best variety of old wheat. The sample mean levels of per acre output for the year 1967/68 in the present study indicate a 52.94 percent increase.[2] Willet (1969) reported a 30-35 percent yield advantage for new wheat.

The indirect cost function estimates indicate a 15.54 percent downward shift in the long-run cost function of wheat resulting from the introduction of new wheat varieties. This is an important finding with implications for the resultant resource savings. During the year 1970/71 India produced about 21 million tons of wheat worth about 16 billion rupees nearly all of which was new wheat. If there had been no new wheats, this amount of wheat could have been produced only with 18.40 percent more resources.[3]

Interesting implications emerge from a comparison of the per acre input demand functions for new and old wheats. The estimated magnitude of the upward shift in the per acre demand functions for labor, fertilizer and other capital inputs, resulting from the introduction of new wheats is 25 percent. Percentage of wheat land planted to new wheat varieties in Punjab was 3.6, 35.4, 48.5 and 65.5 during the years 1966/67, 1967/68, 1968/69 and 1969/70 respectively, and during the year 1970/71 it was almost 100 percent. If we assume a perfectly elastic

---

[1] See Appendix Table I.4, page 188. Also see Khem Singh Gill (1970).

[2] See footnote on page 54, Chapter IV.

[3] As was pointed out in footnote 2 on page 51, in Chapter IV, this result could be used to compute a rate of return to the applied research effort which India made for adapting the new wheat seeds if information on research expenditures was available.

supply of labor the estimated increase in labor absorption in wheat production in the state resulting from new wheats should have been 0.9 percent, 8.85 percent, 12.13 percent, 16.38 percent and 25 percent during the years 1966/67, 1967/68, 1968/69, 1969/70 and 1970/71 respectively. It should be emphasized that these estimates pertain only to the expansion of labor absorption in wheat production. Estimates of the extent to which employment opportunities increased in farming by increased multiple cropping (made possible by the shorter growing period of new wheats) and in other agriculture-related sectors of the economy do not seem to be feasible at this time. Some observers[1/] feel that the indirect effects on expansion of employment perhaps exceed the direct effects. Thus, there seems to be substantial labor absorptive capacity in the 'green revolution'. Since, as a matter of government policy, chemical fertilizer was supplied at a given price all over the state, we can assume perfectly elastic supply of chemical fertilizer. Then the implications for increased use of fertilizer in wheat production due to a shift of the per acre fertilizer demand function resulting from new wheats are the same as in the case of labor. Similarly, increases in the use of other forms of capital would be expected, their magnitude depending upon the supply elasticities of various forms of capital.

The case of land is, however, different. Due to the relatively inelastic supply of land, the increased land productivity that resulted

---

[1/] See for example Robert d'A. Shaw (1970, p. 52).

from the introduction of new wheats became a windfall gain to the owners of farm land--a gain in the form of increased land values at almost no cost to the owners. These gains, of course, were in addition to gains in net income that resulted from the new wheats. The absolute magnitude of gain both from increased land values and the increased net-incomes from the new wheats, increases linearly with the amount of land owned. This increased existing inequalities of income distribution in rural areas of Punjab in favor of the larger land owners.

Results pertaining to new wheat obtained from the four years' data are presented in Chapter V. We provide brief notes on each of them.

The evidence supports the hypothesis of constant returns to scale for new wheat. This finding also holds in the case of old wheat as indicated by the results in Chapter IV, as well as for small and large farms and tractor and non-tractor farms as indicated by the results in Chapters VI and VII respectively. In the cost function model, our estimating equation does not include the price of capital input, because we do not have data on this variable. But, since the 'price' of capital *a priori* is negatively correlated with the output of wheat, we know its omission from the estimating equation biases downward the estimated coefficient $\frac{1}{\gamma}$ for logarithm of output. This in turn imparts an upward bias to the estimate for returns to scale. Hence, the cost function model indicates somewhat increasing returns to scale. By and large, from our analysis, there is no strong evidence against the phenomenon of constant returns to scale in the production of new wheat.

The conclusion is consistent with the findings of numerous earlier studies of Indian agriculture.[1] In the context of the present day political and social climate in India this conclusion has important policy implications. We discuss these in the last section of this chapter, in conjunction with the findings on farm size efficiency.

The best possible estimates for output elasticities, with respect to labor, land and capital inputs as obtained from the profit function formulation and based on four years' data, are 0.224, 0.529 and 0.247 respectively. These estimates have the advantage of being statistically consistent. If the production function is specified treating fertilizer as a separate variable, the results obtained from the direct estimation of the production function yield output elasticities with respect to labor, land, capital (without fertilizer) and fertilizer as 0.194, 0.500, 0.244 and 0.068, respectively. Again these estimates compare quite favorably with those from the earlier Indian studies cited above. Also, since these results are obtained from data for four years they could be expected to provide a more reliable set of estimates for policy predictions relating to wheat production than any cross-section estimates for a single year.

But in the case of the output elasticity with respect to animal power when it is treated as a separate input in the production function, we have not been so fortunate. The best that we could get is an

---

[1] To cite a few see Lau and Yotopoulos (1971, 1972), C. H. H. Rao (1965), G. R. Saini (1969, 1971), V. Chennareddy (1967), W. David Hopper (1965) and A. M. Khusro (1964). Using a different technique, P. K. Bardhan (1972) also found no evidence against the hypothesis of constant returns to scale.

elasticity estimate of 0.014. Draft animals still play an important role in Indian agriculture and this estimate seems to be rather small. It also has as large a standard error as the estimate itself. The problems of measuring the flow of animal power services were acute because of variation in the quality of these services due to age, health, size, breed and feeding of the animals and intensity of their use, etc. But there was also another complication. A large number of tractor farms in the sample had relatively small input of animal power. Thus, in the data used in this investigation very weak and sometimes negative simple correlation existed between the logarithms of output of wheat and animal power. This explains a weak estimate of the coefficient for animal power. But the expenditure share of animal power in total revenue at the level of the sample geometric mean is 0.078 which suggests that animal power is still an important input. Some earlier studies,[1/] however, indicate considerably larger output elasticity with respect to animal power than our estimate. This seems to suggest that the importance of animal power in the sample studied may have declined relative to the earlier periods even though the variable is still quite important.

The results of introducing farmers' education explicitly in the production function analysis as a factor of production indicate that education does enter the wheat production function in a significant

---

[1/] Studies by G. R. Saini (1969), W. David Hopper (1965) and S. V. Sethuraman (1970, p. 19) indicate the output elasticity with respect to animal power to be 0.256, 0.508 and 0.212 to 0.370 respectively.

way. The capitalized value (using a discount rate of 5 percent) of a meager amount of 2.49 years of education per average household member is equal to rupees 3073.73 for our sample. As argued in Chapter V there are reasons to believe that the estimated coefficient of 0.036 used in these computations is a serious underestimate. If we were able to estimate--for the farms to which our data apply--a gross-sales (or value added) production function for all crops, a considerably larger coefficient for education might be expected. Farmer's education seems to be an important factor of production.

The empirical estimates for the profit function model can be employed to obtain a number of elasticity measures which are important for shaping economic policies. From the results in the last column of Table 5.8, the labor demand elasticities with respect to wage rate, quantities of land and capital and the price of wheat are -1.290, 0.682, 0.318 and 1.290 respectively. The output responses of the firm with respect to normalized wage rate, price of wheat and exogenous changes in the quantities of land and capital are -0.290, 0.290, 0.682 and 0.318 respectively. All these elasticity measures are important in obvious ways.

The results of Chapter V also throw some light on an important phenomenon in the production of new wheats which has been taking place during the four year period under investigation. The results indicate that the new wheat production function was stable during the four years in the sense that output elasticities with respect to various inputs do not show statistically significant changes. On the other hand there have been significant changes in the efficiency parameter of the production function after 1967/68. The estimates of these changes obtained from the profit function formulation indicate that, compared to the year 1967/68, the efficiency parameters were lower during the years 1968/69, 1969/70 and 1970/71 to the extent of 22.1 percent, 18.9 percent and 10.4 percent respectively. After the first big decline during 1968/69 the efficiency parameter rose during the next two years. The decline in the efficiency parameter of the production function after 1967/68 could have been due to adverse weather, defective seed quality, and addition of inferior lands to wheat production after 1967/68. Whether this is a continuous technological regression (genetic degeneration of seed) in the production of new wheat is an important question to be investigated by agronomists and plant breeders. To the extent that the deterioration of seed through mixing has been responsible for this decline in efficiency, the point has obvious implications for public seed policy.

From the above discussion it is clear that the corresponding long-run cost function for new wheats shifted upward relative to 1967/68. The magnitudes of these comparisons indicated by the cost function model are of the order of 40.2 percent for 1968/69, 41.6 percent for 1969/70 and 32.7 percent for 1970/71. These shifts are of course the combined result of decline in the efficiency of the production function and a rise in the average level of input prices relative to 1967/68. The rupees per quintal costs calculated at the geometric means from each years' sample were 50.91 for 1967/68, 72.97 for 1968/69, 70.81 for 1969/70 and 69.41 for 1970/71.

From the comparative efficiency analysis of small[1] versus large wheat farms presented in Chapter VI and tractor-operated versus non-tractor-operated wheat farms presented in Chapter VII the following major conclusions emerge:

1. Small and large farms operate on the same production function for new wheat with no neutral or non-neutral differences. The conclusion holds verbatim for tractor and non-tractor farms.

2. No differences are observed in the technical efficiency, price (or allocative) efficiency with respect to labor use and over-all economic efficiency of small and large farms. The conclusion holds for tractor and non-tractor farms as well.

3. For the "tractor cultivation sample 1969/70," there are no observed differences in the land productivity and unit costs of producing wheat at the respective output mean levels of tractor and non-tractor farms--Tables 7.1 and 7.2.

4. Calculated at respective sample means, on an average non-tractor farms employ 367 percent more animal power, 30 percent more labor but 50 percent less physical capital per acre than tractor farms--Tables 7.1 and 7.2.

5. As was pointed out earlier there is no evidence against the phenomenon of constant returns to scale on small farms, large farms, tractor-operated farms or non-tractor-operated farms.

6. From the profit function formulation we tested the hypothesis of profit-maximizing behavior (or rationality) of small and large wheat farmers. Specifically we tested whether wheat producers were

---

[1] Small wheat farms are defined as those producing 10 acres or less of wheat and large farms as those producing more than 10 acres of wheat.

successful in maximizing profits by equating the marginal value product of labor to its opportunity cost, following the shift in labor demand function resulting from the introduction of high-yielding wheats. The results indicate that during the first two years producers were not in equilibrium in the sense that they were equating the marginal value product of labor to its opportunity cost. During the third year the producers seem to be approaching an equilibrium in the sense that the hypothesis of absolute price-efficiency is rejected less strongly than in the first two years. And finally during the last year 1970/71, we find evidence that an equilibrium had been attained. This seems to be an example of short-run disequilibrium being successfully overcome by the rational producer behavior. Small and large farmers over the four years, however, were equally successful (or unsuccessful) in their attempts to maximize profits.

Policy Implications

The implications of the results of this research for policy purposes are straight-forward. The issues involved in agricultural development policies of the developing countries, as they move forward in their efforts to alleviate poverty and improve levels of living of their people, evolve from: (1) the need to obtain maximum potential agricultural output, (2) the need for more productive employment of the rapidly growing labor force, (3) increasing social and political pressures for reducing the inequalities of income distribution, and (4) the problem of attaining a desirable balance among these goals. The findings of this study seem to have a direct bearing on each of these problems.

With regard to the need to realize maximum potential output, we find in the Punjab that the possibilities for growth by improving allocative efficiency in moving toward production frontiers are very limited. Whenever potential improvements are within the reach of the producers, they try to introduce them very quickly. This is the inference from tests indicating that producers behave rationally. On the other hand technical changes which shift the production surface upward constitute the more important source for potential increases of output. The dramatic increase in wheat production following the introduction of high-yielding wheats and the resulting resource savings pointed out by this investigation suggest the desirability of improving production technologies of other crops and livestock. It seems necessary to diversify research effort to cover other agricultural commodities which have high income elasticities of demand. Increasing productivity, incomes and employment as a result of the green revolution are bound to exert pressure on the demand for these commodities. Increased research emphasis thus seems to be necessary if one is interested in maintaining the momentum provided by new wheats.

The windfall gains or increased incomes resulting from the green revolution seem to be proportional to the amount of land owned. We will have permitted unique opportunities to elude our grasp if appropriate fiscal measures are not soon designed to tax away from the land owners some of the windfall gains in incomes and capital values that have resulted from the green revolution at little or no cost. The reinvestment of these gains in research programs and to build agricultural and social infrastructure is necessary to sustain future growth of the economy. Capturing some of these gains is also desirable to reduce increasing income inequalities between owners and laborers.

The considerable labor-absorptive potential of the green revolution is real, as is indicated by our findings. This potential is likely to expand as additional areas come under high-yielding varieties of cereals and other labor-absorbing types of technical developments take place. But the existence of this potential is by itself no guarantee for providing productive employment to the growing labor force. We note that in the case of wheat, high-yielding varieties create a potential for 25 percent increase in the use of labor per acre, and that tractorization replaces 25 percent of the labor per acre. Policies which encourage use of large tractors and combines will obviously enlarge the gap between actual and potential rate of growth in agricultural employment.

From the data analyzed in this study we find that tractor-operated farms are no better in terms of their economic performance than non-tractor operated farms. This situation also holds between larger and smaller farms. This seems to be an inferior performance of tractor-operated farms and of larger farms if we assume that these farms obtain capital subsidies and have relatively greater access to extension services. From our analysis it is difficult to justify subsidization policies which encourage tractorization and displace labor.

The question of agrarian reform, especially the imposition of an upper limit on ownership of land, is currently an important issue in India. From the results of our investigation we can derive some qualified policy implications with respect to this issue. The qualification is necessary because we have studied only the wheat crop out of the complete set of enterprises on Punjab farms. There could be a question that even though constant returns to scale prevail in wheat production, there may be some increasing returns to scale if we study the production relationship between aggregate output of all enterprises and the inputs used. Most earlier studies, however, indicate constant returns to scale in Indian agriculture.

From the analysis of data used in this investigation there seems to be no basis, on the grounds of economic efficiency and under the existing pricing structure, for favoring either smaller or larger farms. In view of these findings, policy of curtailing farm size, for example of farms larger than ten acres under irrigated conditions, may be pursued only on social and political considerations. It may, however, be repeated that our conclusion of equal efficiency between small and large farms seems to be the result of policies that favor larger farms. In the absence of this subsidization policy smaller farms might actually be more efficient as indicated by earlier Indian studies. Smaller farms may also be more desirable from the point of view of India's land and labor endowments, from the considerations of a more equitable rural social structure, and of a productive absorption in agriculture of an expanding labor force. A limit of size should also help in eliminating the demand for large-sized, labor-replacing types of agricultural machinery.

During the past two decades India has pursued quite vigorously policies of expanding primary education in the rural areas. Our results indicate that education of agricultural families is an important factor in agricultural production. India's emphasis on expanding education of rural people has thus been well placed. One may also emphasize that agricultural development strategies should place considerable emphasis on farmers' education. Expansion and improvement in the standards of rural education in India thus seems to be a step in the right direction.

APPENDICES

APPENDIX I

The Context of Punjab Wheat Production

The purpose of this appendix is to describe briefly (1) the agronomic aspects of wheat cultivation in Punjab, (2) soil and agroclimatic zoning of the state, (3) the changing perspective of the 1950's and 1960's with regard to various types of agricultural infrastructure and varietal research work on wheat, and (4) the environment that resulted from the introduction of new wheats.[1/] This discussion will clarify the context in which wheat production is carried out in Punjab and throw some light on the underlying causes of relatively more rapid success of new wheats in Punjab than in other areas. We hope this will enhance our understanding of the 'green revolution.'

1. The Agronomic Aspects of Wheat Production in Punjab

The main emphasis in this study is on the production and cost aspects of wheat production in the Punjab, India. It is not intended to provide detailed discussion of agronomic aspects of wheat cultivation.[2/] A brief review presented in this section is intended to be helpful to keep the relevance of the study in proper focus.

[1/] A geographical description of the area of study is provided in Chapter III, page 41.

[2/] For a detailed discussion of this problem look to the Punjab Agricultural University Publications (Oct. 1970, 1971), Khem Singh Gill (1970) and USAID, Spring Review, March, 1969, p. 59.

Cultural practices and/or requirements for wheat are quite similar across much of the state even though variations exist in the methods of performing various tasks.[1/] The basic process of production involves conversion of inputs like seed, water, plant nutrients from soil and fertilizers, and energy from solar, human, animal and mechanical sources into wheat grain and straw. This input-output transformation relationship seems to be quite uniform in various parts of the state.

Planting of wheat in Punjab starts from November 1 and continues as late as the first week of January. Best yields are obtained for sowings during the first half of November. Most wheat is grown in rotation with some summer crop. This necessitates late planting, particularly when wheat has to follow cotton. But most of the wheat is sown in November after fallow or corn. Plantings of November 22, December 10 and January 10 relative to November 1 are reported (P.A.U., 1971) to reduce output by 10 percent, 25 percent, and 52 percent respectively.

In order to insure proper germination it is essential to plant wheat seed in a well prepared seed bed. For this purpose, the land is irrigated after harvesting the preceeding crop. Necessary plowing and planking operations are then carried out till a smoothed and leveled seed bed is obtained. The nature and intensity of these operations depends upon the soil type and the type of equipment used.

[1/] For a discussion of agricultural tasks see: Inderjit Singh et.al. (1968, pp. 3,4). They define task as a general type of action required in production; examples are plowing, irrigation, planting, etc.

Sowing is done either with a seed cum fertilizer drill or by dropping the seed by hand about 9 inches apart in furrows opened by a wooden plow. About 30-35 kilograms of seed are used per acre. This quantity varies somewhat with the variety, planting time and other sowing conditions. Usually the seed is planted about 2-2.5 inches deep.

Applications of nitrogen (N) and phosphoric pentoxide (P_2O_5) are essential for wheat production in Punjab. For most soils even potash (K_2O) is necessary. Zinc deficiency is being increasingly noticed, particularly on sandy soils. Under average fertility conditions a dose of 50 kilograms of N, 25 kilograms of P_2O_5 and K_2O each is recommended. It is not uncommon to observe considerably higher applications than this on lighter soils and for late plantings. P_2O_5, K_2O and one-half of N are applied at the time of planting and the remaining N at the time of first irrigation. Kahlon and Kaul (1968) have reported that even at fertilization level recommended for old wheats, the new wheats have larger output per acre than the best old variety.

Under normal conditions, 7-9 irrigations are considered necessary for 'New Wheats' for successful maturing of the crop. Crown root formation, late tillering and the time of grain formation have been identified as three physiologically critical stages for irrigation.

2. Soil and Agroclimatic Zoning

Zoning of Punjab soils based on climate and chemical characteristics has been quite well described by Raychaudhari et.al. (1963), Sehgal et.al. (1968), Singh, Day and Johl (1968) and P.A.U. Handbooks (1970 and 1971). It is not the intention to go into full details of this subject. Only a skeleton outline will be developed.

Temperatures in Punjab vary a great deal over the year. But very small variation is observed across the state at any given time. From the temperature side, thus, Punjab is quite a homogeneous zone. There do exist, however, considerable variations in the chemical soil characteristics and rainfall across the state. Table I.1 provides the criteria for demarcating the state into five 'Soil Zones.'[1/] Briefly the five zones are as follows: (i) Comprising of Pathankot tehsil of Gurdaspur district, Una tehsil and parts of Houshiarpur, Dasuya and Garhshankar tehsils of Houshiarpur district and parts of Rupar district. The annual rainfall is 40" to 60". There is a problem of soil erosion by water in this zone. (ii) The remaining areas of Gurdaspur, Houshiarpur and Rupar districts, most parts of Jullundur, Kapurthala Patiala and Amritsar. Normal annual rainfall is 30"-40". Salinity and drainage are problems in parts of the area. (iii) Parts of Amritsar, Jullundar, Kapurthala, Ludhiana, Patiala and Sangrur districts. The normal annual rainfall varies from 20"-30". Patches of salinity and some wind and water erosion problems exist. (iv) Bhatinda district and parts of Sangrur and Ferozepur districts. Normal annual rainfall varies from 10"-20". Salinity and wind

---

[1/] These 'Soil Zones' are sometimes referred to as 'Agroclimatic Regions.'

erosion are problems. (v) This is the extreme southwestern area of the state with less than 10" rainfall, and comprises parts of Ferozepur district.

TABLE I.1

SOIL ZONES OF THE PUNJAB, INDIA

Zone	Soil Characteristics						Available Nitrogen Kgs/Acre	Available P_2O_5 Kgs/Acre	Rainfall in Inches
	pH Range	$CaCO_3$ %	Organic Matter %	Nitrogen %	P_2O_5 %	K_2O %			
(i)	6.5-7.5	0.16	1.00	0.08	0.16	0.69	51.79	6.87	40-60
(ii)	7.0-8.5	0.17	0.80	0.06	0.12	0.66	44.51	8.49	30-40
(iii)	7.5-8.5	0.24	0.53	0.01	0.14	0.45	44.91	8.90	20-30
(iv)	8.0-8.6	1.84	0.50	0.04	0.15	0.77	35.61	8.09	10-20
(v)	8.5-9.0	2.30	0.23	0.02	---	---	33.99	7.28	<10

Source: Punjab Agricultural Handbook (1970, p. 96) and Singh, Day and Johl, (1968, p. 19).

This classification overlaps slightly with the demarcation of farming areas by Singh, Day and Johl (1968) and subsequently suggested cropping pattern in Punjab by Johl and Sandhu (1970). The overlap, however, is not large.

Wheat is grown practically all over the state, but zones (i) and (v) are relatively less important.

3. The Changing Perspective of the 1950's and 1960's

During the decades of fifties and sixties Punjab underwent tremendous changes. The state had two major revisions of its geographical and administrative boundaries, experienced significant agricultural growth, made considerable land and water investments and improved agricultural research capacity. Also numerous mechanical innovations of various kinds were introduced. From Table I.2 we note that the spread of new wheat varieties in Punjab during the late sixties was more rapid than in other wheat-growing areas. One might conclude that the pre-existence of agricultural infrastructure perhaps led to a more rapid acceptance and diffusion of the new wheat technology in Punjab.[1/] In this section we develop a brief perspective of these developments which might provide some insight into the underlying causes of this success. This will improve our understanding of 'green revolution' and help in designing agricultural development strategies in India and elsewhere.

In Table I.3 we provide a summary of the growth process of Punjab agriculture during the period 1950/51 to 1969/70, as reflected by a few selected growth indicators. Priot to the start of the 'green revolution' in 1965/66 there were continuing increases in irrigation potential and agricultural production. In particular, we note quite rapid increases in total and per acre output of wheat. After 1964/65, with the introduction of high-yielding varieties of wheat, these increases became more rapid.

[1/] For an exposition and test of the hypothesis that complementarity between infrastructure and research and development effort is important for agricultural growth, see Hsieh and Ruttan (1967).

TABLE I.2

PERCENT OF WHEAT AREA PLANTED TO NEW WHEATS IN WHEAT-GROWING STATES IN INDIA, 1966/67 to 1969/70

State	1966/67	1967/68	1968/69	1969/70
Punjab	3.6	35.4	48.5	65.5
Uttar Pradesh	8.3	31.9	48.0	52.8
Haryana	1.8	12.0	28.9	43.8
Bihar	3.1	18.9	27.5	37.1
Gujrat	0.1	29.1	33.3	37.0
Rajasthan	1.0	9.9	16.4	23.3
Maharashtra	4.9	1.5	7.3	16.8
Madhya Pradesh	0.8	1.7	2.7	4.9
All India	4.3	20.1	30.5	37.0

Source: Martin E. Abel (November 1971), pp. 37, 38.

During the 1950's and early 1960's, the state of Punjab followed a vigorous policy of consolidating scattered and fragmented holdings of land into larger operating units. This provided an impetus to land and water investments. At the same time investments in other infrastructure like roads, generation of power, building of agricultural research facilities, design and promotion of agricultural implements and equipment, etc., also were made at an equally rapid rate. It is usually argued that new varieties of wheat need better irrigation

TABLE I.3

SOME SELECTED GROWTH INDICATORS, 1950/51 - 1969/70
PUNJAB, INDIA

S.No.	Growth Indicator	1950/51	1960/61	1964/65	1969/70
1.	Net Area Sown (000 acres)		9,284 (100.00)	9,622 (103.64)	9,951 (107.18)
2.	Total Area Cropped (000 acres)		11,693 (100.00)	12,644 (108.30)	13,653 (116.76)
3.	Wheat Area (000 acres)	2,809 (100.00)	3,460 (122.60) (100.00)	3,830 (137.47) (110.69)	5,414 (192.74) (156.47)
4.	Production of Wheat (000 metric tons)	1,024 (100.00)	1,725 (168.46) (100.00)	2,360 (230.47) (136.81)	4,918 (480.27) (285.10)
5.	Per Acre Output of Wheat (Kgs)	365 (100.00)	501 (137.26) (100.00)	611 (167.40) (121.96)	909 (249.04) (181.44)
6.	Percent of Cropped Area Irrigated	45.39	56.0	59.4	74.0
7.	Irrigation tube wells (No.)			26,066[a] (100.00)	87,562 (359.92)
8.	Tractors (No.)		4,935[b] (100.00)	10,636[b] (215.52)	25,000[c] (560.56)
9.	Diesel Engines and Electric Motors (No.)		13,565[b] (100.00)	45,903[b] (338.39)	116,000[d] (855.14)

TABLE I.3
(continued)

S.No.	Growth Indicator	1950/51	1960/61	1964/65	1969/70
10.	Fertilizer Used (metric tons)		49,162 (100.00)	232,230 (472.38)	534,101 (1,086.41)
11.	Index of Agricultural Production 1961-62 = 100	(59.34)	(103.31)	(127.71)	(200.18)

Notes: For serial numbers 1 to 7 and 10, Statistical Abstract of Punjab, 1970--Tables 3.7, 3.8, 3.19, 3.43, 4.3 and 4.6--is the basic source of information.
For serial numbers 8, 9 and 11, see S.S.Johl (1970).
For estimates c and d in serial numbers 8 and 9 respectively see Pathak (May 1970), pages 5.6.

[a] Figure pertains to year 1965/66.

[b] Figures in serial numbers 8 and 9 pertain to year 1961 instead of 1960/61 and 1966 instead of 1964/65.

Figures in parentheses are index numbers.

facilities because of their heavier and timely demand for irrigation. They need quick and timely harvesting because of their quick maturity. And, in order to take advantage of their shorter growing period to increase multiple cropping, faster seedbed preparation is required. Perhaps in Punjab these requisites for a successful introduction of the new wheat varieties were available relatively more than in other wheat growing regions of India. Their acceptance rate will obviously be slower in areas lacking these facilities.[1]

Varietal Research

Research input is well recognized complement of infrastructure capacity for agricultural growth. In Punjab research on wheat improvement was started in early 1900's at Layallpur (now in Pakistan). In 1934, two famous Punjab Wheats, C591 and C518 were developed.[2] These varieties soon became very popular in vast areas of Punjab and other states in India and were still grown as late as mid-fifties.

After partition of India somewhat more location-specific research was emphasized in Indian Punjab. During the fifties two excellent varieties, C273 for general Punjab conditions, and C286 for humid (sub-montane) areas were developed. In 1965, the latest in the series, a variety C306 was released by Punjab Agricultural University. It was

---

[1] See Billings and Singh (Jan. 1971, page 102) for further development of this point. For differential acceptance rates of high-yielding wheat varieties see Lockwood et. al. (1971) and Schluter (Aug. 1971).

[2] An excellent brief discussion of these early pioneering efforts in wheat breeding is provided by Gill (June, July 1970) and Roberts and Singh (1947, pp. 220-244).

considered to be the best variety among the Indian wheats and was recommended all over northern India. Simultaneously Indian Agricultural Research Institute in Delhi bred certain good wheat varieties like NP852, NP839 and NP404. The early improved varieties of mid-thirties replaced the local unimproved wheats and subsequently improved strains continued to substitute for the older ones. During early sizties nearly all wheat grown in Punjab (which then included Haryana) was of the improved type. These developments and continuous increases in controlled irrigation and other associated technology, thus, provided a steady (though not spectacular) growth in agricultural productivity before the 'green revolution.'

Until the early 1960's the Indian wheat breeding program, however, appears to have been operating under three constraints. One or another form of rust has been a serious problem with most Indian wheats. Breeding of rust-resistant strains therefore, was considered essential. Secondly, amber grain character was considered necessary because of consumer preference. These two factors necessitated backcrossing with existing superior Indian varieties. Thirdly all Indian wheats are tall-growing (attain a plant height up to 53.14 inches), have tender straw and are susceptible to lodging under heavy fertility conditions. In case of rains and heavy winds during late March, lodging occurs even under conditions of low fertility. This characteristic of Indian wheat varieties remained a limiting factor for increasing their yield per acre. Thus, even though the improved Indian wheat varieties helped to raise and stabilize wheat production in Punjab (and India) they suffer from a low 'yield ceiling.' Their maximum obtainable yield potential was limited to 12-16 quintals per acre. This constituted a major barrier to increased wheat production in India.

Around 1960, particularly in 1961, the problem of yield ceilings was being felt acutely.[1/] Intensive fertilizer demonstrations on farmer's fields contributed to this increased awareness. By 1962, wheat breeders in India were convinced that dwarf wheat varieties are essential for breaking the yield stagnation of this crop. Some observation trials were conducted with a group of dwarf Mexican varieties in 1962/63. This led to a request by Government of India to the Rockefeller Foundation to enter into a joint coordinated program on wheat development. Dr. Norman E. Borlaug of the International Wheat and Maize Improvement Center in Mexico was invited to India to study and advise on the possibility of dwarf wheat production in India.[2/]

After visiting the wheat growing regions of India, Dr. Borlaug concluded that climatically they were quite similar to Mexico and in 1963 supplied 100 kgs of seed for four semi-dwarf varieties (Mayo 64, Sonora 63, Sonora 64, Lerma Rojo 64A and small samples of 613 other promising selections. Some commercial seed quantities were also obtained from Mexico during this year. The breeding material was planted and assessed at 6 places including Punjab Agricultural

---

[1/]Material in this section is condensed from Khem Singh Gill (1970) and USAID, Spring Review, March, 1969.

[2/]For brief reviews of the evolution of dwarf wheats see Ralph and Lorang (July, 1969), Khem Singh Gill (op. cit.,) & USAID, Spring Review (March 1969), p. 9-10).

University, Ludhiana and IARI, New Delhi. Yields of up to 16.18 quintals per acre were obtained for Sonora 64 and Lerma Rojo 64A. Dwarf varieties were also tested rigorously for rusts and quality during 1964/65. In 1965, 250 tons of Sonora 64 and Lerma Rojo were imported which were distributed to state seed farms and to more than 5,000 farmers for 1965/66 planting.

Ever since new wheats were introducted in India, the adaptive research effort in India concentrated not only on ecological adaptation of the dwarf wheat but also on developing amber and white varieties in view of the demand preferences of the Indian consumer. Through reselection from the original breeding material supplied by Dr. Borlaug, Indian scientists developed several such varieties. A few of them were released as follows: PV 18 (1966); Kalyan Sona (1967); S308 (1968); Sonalika (1967); Safed Lerma (1967); Sharbati Sonora (1967); S331 (1967). The first three varieties are now extensively grown in Punjab. Their relative performances compared to the best native variety C306 are given in Table I.4. Kalyan Sona has become relatively more popular because of its good quality for making chapatties (Indian freshly baked bread). Its performance also is good under high and low fertility as well as late sown conditions.

The introduction of dwarf wheat varieties from Mexico and subsequent development of new wheats through reselection and adaptive research provided India with a technological 'break-through', breaking the yield ceiling which prevailed in case of old varieties in India.

TABLE I.4

RELATIVE PERFORMANCE OF NEW WHEATS VS. C306
PUNJAB AGRICULTURAL UNIVERSITY, LUDHIANA

Variety	Height of plant in cms.	Color of grain	Yield in quintals per acre		Gross returns Rs/acre
			Potential	Average	
(New Wheats)					
PV 18	90	Red	24.25	18.2	1438
Kalyam Sona	90	Amber	24.25	17.8	1407
S308	105	Amber	22.26	17.0	1347
(Native Wheat)					
C306	135	Amber	16.18	10.5	878

Source: Khem Singh Gill (June, July 1970, pp. 3, 9A): Punjab Agricultural University. (Research Results)

4. After the Break-through

The yields of dwarf wheats obtained during 1965/66 both by farmers and seed farms were very encouraging. For the crop year 1966/67, 18,000 tons of seed for Lerma Rojo 64A and a few other varieties were imported and about 1 million acres were planted to dwarf wheats in India. In Punjab about 3.6 percent of its wheat area was planted to Mexican varieties, mainly Lerma Rojo 64A. Yield differentials with the old wheat varieties were tremendous. Since then farmers multiplied and spread these varieties practically to all wheat lands in India.

Dwarf varieties were reported (Willet, July 1969, p. 10) to have a 30-35 percent yield advantage over the Indian wheats. Information presented in Table I.4 above indicates, that under experimental conditions, the adapted varieties had a substantially larger (about 62 percent) yield advantage over the native wheats. That new wheats had substantially higher output than Indian wheats per unit of land, thus, hardly seemed to be doubted.

New wheats, however, require a new agronomic approach. Yield advantages are obtainable under certain specified agronomic requirements. During their early introduction relatively more fertile lands were devoted to their production. Required irrigation, labor and fertilizer inputs per unit of land are substantially greater than old varieties. Irrigation and planting must be carefully controlled to achieve the increased response to higher levels of fertilization. Thus, not only is the output rate higher in case of new wheats, so also is the rate of inputs per unit of land. In view of these differential input rates of the two wheats and higher output price for the old wheats, the relative profitability of the two wheats from grower's point of view was conjectural. And there had been some question as to whether the unit costs of new wheats are lower than the old wheats.

As pointed out earlier, farming in Punjab had been passing through a rapid transformation. The input mix had been continuously changing. Information on production costs during late 1960's was not available. Change in the behavior of costs with the introduction of new wheats and the accompanying chemical technology was a matter of speculation.

Put another way whether the long-run cost function for wheat shifted downward with the introduction of new wheats was not clear.

Evidence on the controversial nature of this matter comes from Dalrymple. Willet (July 1969) quotes him as saying, ". . ., although there have been a few farm management studies of costs and returns, there is insufficient basis to generalize to aggregate supply functions which could predict the overall response of output to price changes." Authors of USAID, Spring Review (March, 1969, pp. 29, 32) discussing the level of procurement-prices also recognized the lack of information about costs of production as a problem and observed, ". . . Cost of production studies as yet, have not given much guidance in these calculations.--Information on supply response to price of Indian food-grain production on which to base these calculations is scarce." It was this environment of uncertainty about the nature of change in the production and cost relationships following the introduction of new wheats, that motivated this study.

APPENDIX II

Test for the Maintained Cobb-Douglas Hypothesis

The CES (Constant Elasticity of Substitution) production function with nonconstant returns to scale is given by

(1) $$Y = \gamma[\delta N^{-\rho} + (1-\delta) K^{-\rho}]^{-\mu/\rho}$$

where

- Y is output of wheat per farm in physical units
- N is labor hours per farm used for wheat production
- K is total capital per farm including land rent
- γ is the efficiency parameter
- δ is labor intensity parameter
- μ represents the degree of homogeneity of the function or the degree of returns to scale, and
- ρ defines the elasticity of substitution as: $\sigma = \frac{1}{1+\rho}$.

Following Kmenta (1964, 1967), a logarithmic approximation of (1) up to a second order can be obtained by discarding terms of higher order as follows:

(2) $$\ln Y = \ln \gamma + \mu\delta \ln N + \mu(1-\delta) \ln K - \frac{\mu\rho}{2} \delta(1-\delta) [\ln N - \ln K]^2 + V$$

where

V is the measure of the neglected higher-order terms.

In (2) the term involving the square of the logarithm of labor-capital ratio makes it different from the usual two-input, Cobb-Douglas production function. If σ is different from one, p should be significantly different from zero and the coefficient of the square of logarithm of labor-capital ratio should show up as significant.

The estimates for equation (2) for new wheat using data for the years 1967/68 - 1970/71 are presented as (3) and (4).

$$(3) \quad \ln Y = \underset{(0.399)}{-3.560} + \underset{(0.041)}{0.222} \ln N + \underset{(0.117)}{0.749} \ln K + \underset{(0.007)}{0.001} [\ln N - \ln K]^2$$

$$R^2 = 0.905$$

$$(4) \quad \ln Y = \underset{(0.383)}{-4.141} - \underset{(0.047)}{0.406}D_1 - \underset{(0.044)}{0.380}D_2 - \underset{(0.048)}{0.303}D_3 + \underset{(0.039)}{0.203} \ln N + \underset{(0.113)}{0.945} \ln K - \underset{(0.007)}{0.007} [\ln N - \ln K]^2$$

$$R^2 = 0.916$$

The coefficient for $(\ln N/K)^2$ is not significantly different from zero in both (3) and (4) at normally accepted significance levels. In equation (4) year 'effects' are captured by introducing year dummies D_1, D_2 and D_3 which take the value of one for 1968/69, 1969/70, 1970/71 respectively and zero otherwise. This improves the fit of the equation slightly but the coefficient for $(\ln N/K)^2$ still remains nonsignificant. For these data, thus, we cannot reject the hypothesis that elasticity of substitution between labor and capital is unity which implies that the Cobb-Douglas form should be an adequate representation for it.

Note: In equations (3) and (4) figures in parenthesis are the standard errors.

APPENDIX III

ZERO-ORDER CORRELATIONS

TABLE III.1 ZERO-ORDER CORRELATION MATRICES, LOGARITHMS OF VARIABLES

(Old and new wheats pooled, 1967/68)

	Y	N	L	K	K_1	K_2	B	F	E	wN	T	w	t	C
Y	1.00													
N	0.91	1.00												
L	0.94	0.92	1.00											
K	0.94	0.93	0.94	1.00										
K_1	0.91	0.88	0.91	0.95	1.00									
K_2	0.93	0.93	0.94	0.98	0.96	1.00								
B	0.48	0.55	0.53	0.54	0.39	0.57	1.00							
F	0.60	0.51	0.48	0.63	0.56	0.54	0.18	1.00						
E	0.05	0.01	0.01	0.02	0.05	0.01	0.01	0.05	1.00					
wN	0.91	0.97	0.90	0.93	0.87	0.92	0.55	0.53	0.02	1.00				
T	0.91	0.88	0.94	0.91	0.87	0.91	0.52	0.46	-0.01	0.87	1.00			
w	0.31	0.20	0.24	0.27	0.25	0.27	0.19	0.25	0.04	0.43	0.25	1.00		
t	0.01	-0.01	-0.08	-0.01	-0.06	-0.02	0.03	-0.02	-0.06	0.00	-0.06	0.05	1.00	
C	0.96	0.96	0.96	0.98	0.94	0.98	0.55	0.57	0.01	0.96	0.95	0.32	0.06	1.00

(New Wheat, 1967/68)

	Y	N	L	K	K_1	K_2	B	F	E	wN	T	w	t	C
Y	1.00													
N	0.94	1.00												
L	0.96	0.93	1.00											
K	0.96	0.96	0.96	1.00										
K_1	0.94	0.92	0.95	0.97	1.00									
K_2	0.96	0.95	0.96	0.99	0.98	1.00								
B	0.57	0.60	0.59	0.61	0.50	0.62	1.00							
F	0.86	0.86	0.84	0.89	0.83	0.84	0.48	1.00						
E	0.05	0.05	0.02	0.04	0.05	0.03	0.09	0.06	1.00					
wN	0.94	0.98	0.93	0.95	0.91	0.94	0.61	0.86	0.04	1.00				
T	0.96	0.93	0.97	0.96	0.93	0.95	0.57	0.86	0.02	0.93	1.00			
w	0.45	0.39	0.41	0.42	0.38	0.41	0.34	0.39	-0.01	0.56	0.42	1.00		
t	0.03	0.02	-0.10	0.02	-0.02	-0.01	-0.08	0.11	0.03	0.04	0.16	0.08	1.00	
C	0.97	0.97	0.97	0.99	0.96	0.98	0.61	0.89	0.03	0.97	0.98	0.46	0.05	1.00

Note: For definition of the variables see Chapter III.

TABLE III.1 (continued)

(New Wheat, 1968/69)

	Y	N	L	K	K_1	K_2	B	F	E	wN	T	w	t	C
Y	1.00													
N	0.92	1.00												
L	0.93	0.97	1.00											
K	0.92	0.96	0.96	1.00										
K_1	0.89	0.94	0.95	0.97	1.00									
K_2	0.90	0.96	0.95	0.99	0.97	1.00								
B	0.30	0.34	0.31	0.36	0.24	0.38	1.00							
F	0.79	0.78	0.77	0.82	0.76	0.76	0.24	1.00						
E	0.05	-0.05	0.02	0.02	0.03	0.02	-0.01	-0.01	1.00					
wN	0.89	0.97	0.95	0.95	0.92	0.94	0.34	0.77	-0.05	1.00				
T	0.91	0.93	0.97	0.93	0.91	0.92	0.36	0.75	0.02	0.91	1.00			
w	0.12	0.13	0.15	0.18	0.15	0.17	0.10	0.15	-0.02	0.35	0.16	1.00		
t	0.28	0.22	0.23	0.25	0.18	0.24	0.30	0.19	0.02	0.22	0.48	0.08	1.00	
C	0.93	0.97	0.98	0.99	0.96	0.98	0.37	0.80	0.01	0.97	0.97	0.21	0.32	1.00

(New Wheat, 1969/70)

	Y	N	L	K	K_1	K_2	B	F	E	wN	T	w	t	C
Y	1.00													
N	0.87	1.00												
L	0.93	0.91	1.00											
K	0.89	0.87	0.92	1.00										
K_1	0.87	0.79	0.88	0.93	1.00									
K_2	0.87	0.87	0.90	0.98	0.93	1.00								
B	-0.01	0.15	0.06	0.06	-0.16	0.09	1.00							
F	0.66	0.60	0.67	0.74	0.65	0.65	-0.01	1.00						
wN	0.86	0.96	0.89	0.85	0.77	0.84	0.14	0.59		1.00				
T	0.92	0.85	0.92	0.88	.84	0.87	0.04	0.63		0.86	1.00			
w	-0.02	-0.10	-0.04	-0.05	-0.04	-0.05	-0.03	0.00		0.18	0.00	1.00		
t	-0.01	-0.08	-0.17	-0.06	-0.09	-0.05	-0.05	-0.08		-0.05	0.22	0.11	1.00	
C	0.93	0.93	0.95	0.97	0.90	0.95	0.07	0.70		0.93	0.96	0.02	0.04	1.00

Note: For definition of the variables see Chapter III.

TABLE III.1 (continued)

(New Wheat, 1970/71)

	Y	N	L	K	K_1	K_2	B	F	E	wN	T	w	t	C
Y	1.00													
N	0.95	1.00												
L	0.94	0.95	1.00											
K	0.94	0.93	0.94	1.00										
K_1	0.88	0.87	0.90	0.94	1.00									
K_2	0.91	0.91	0.92	0.98	0.95	1.00								
B	0.24	0.30	0.22	0.25	0.08	0.25	1.00							
F	0.82	0.79	0.81	0.83	0.73	0.75	0.19	1.00						
E	0.06	0.04	0.03	0.07	0.01	0.05	-0.04	0.12	1.00					
wN	0.92	0.98	0.94	0.91	0.87	0.89	0.26	0.75	0.02	1.00				
T	0.95	0.92	0.95	0.92	0.86	0.89	0.22	0.80	0.07	0.89	1.00			
w	0.12	0.14	0.16	0.09	0.19	0.11	-0.15	0.04	-0.05	0.34	0.07	1.00		
t	0.48	0.39	0.35	0.40	0.32	0.36	0.11	0.38	0.15	0.33	0.62	-0.21	1.00	
C	0.97	0.97	0.97	0.98	0.92	0.96	0.25	0.83	0.07	0.96	0.97	0.16	0.47	1.00

(New Wheat, 1967/68, 1968/69 and 1970/71)

	Y	N	L	K	K_1	K_2	B	F	E	wN	T	w	t	C
Y	1.00													
N	0.93	1.00												
L	0.95	0.95	1.00											
K	0.95	0.96	0.96	1.00										
K_1	0.92	0.92	0.94	0.97	1.00									
K_2	0.93	0.95	0.96	0.99	0.97	1.00								
B	0.48	0.53	0.50	0.52	0.39	0.54	1.00							
F	0.82	0.81	0.79	0.84	0.78	0.78	0.37	1.00						
E	0.01	-0.05	-0.03	-0.01	0.00	-0.02	-0.04	-0.01	1.00					
wN	0.92	0.98	0.94	0.94	0.90	0.94	0.53	0.80	-0.07	1.00				
T	0.93	0.94	0.96	0.95	0.91	0.94	0.51	0.79	-0.03	0.93	1.00			
w	0.35	0.35	0.35	0.35	0.31	0.35	0.25	0.29	-0.12	0.52	0.35	1.00		
t	0.32	0.32	0.26	0.32	0.26	0.30	0.23	0.30	-0.03	0.33	0.51	0.16	1.00	
C	0.96	0.98	0.98	0.98	0.95	0.98	0.53	0.83	-0.03	0.97	0.98	0.40	0.39	1.00

Note: For definition of the variables see Chapter III.

TABLE III.1 (continued)

(New Wheat, 1967/68, 1968/69, 1969/70, 1970/71)

	Y	N	L	K	K_1	K_2	B	F	wN	T	w	t	C
Y	1.00												
N	0.92	1.00											
L	0.95	0.94	1.00										
K	0.93	0.94	0.95	1.00									
K_1	0.90	0.88	0.92	0.95	1.00								
K_2	0.92	0.93	0.95	0.99	0.96	1.00							
B	0.31	0.40	0.34	0.36	0.18	0.37	1.00						
F	0.76	0.74	0.75	0.81	0.74	0.74	0.22	1.00					
wN	0.91	0.98	0.93	0.92	0.86	0.92	0.40	0.73	1.00				
T	0.93	0.93	0.96	0.93	0.89	0.92	0.35	0.73	0.91	1.00			
w	0.21	0.19	0.20	0.19	0.17	0.20	0.14	0.17	0.40	0.22	1.00		
t	0.24	0.22	0.16	0.23	0.16	0.22	0.13	0.17	0.24	0.44	0.13	1.00	
C	0.95	0.97	0.97	0.98	0.93	0.97	0.37	0.78	0.96	0.97	0.26	0.31	1.00

Note: For definition of the variables see Chapter III.

TABLE III.1 (continued)

	Y	N	L	K	K_1	K_2	B	F	wN	T	w	t	C
	(New wheat 1969/70,---tractor farms)												
Y	1.00												
N	0.84	1.00											
L	0.86	0.88	1.00										
K	0.80	0.78	0.85	1.00									
K_1	0.77	0.70	0.77	0.93	1.00								
K_2	0.79	0.76	0.82	0.97	0.97	1.00							
B	-0.17	-0.03	-0.00	-0.07	-0.25	-0.08	1.00						
F	0.59	0.60	0.67	0.74	0.55	0.58	-0.01	1.00					
wN	0.80	0.93	0.85	0.76	0.69	0.74	-0.02	0.61	1.00				
T	0.86	0.79	0.83	0.79	0.74	0.77	-0.11	0.57	0.79	1.00			
w											1.00		
t												1.00	
C	0.88	0.87	0.91	0.94	0.88	0.91	-0.08	0.70	0.88	0.93			1.00
	(New wheat 1969/70,---non-tractor farms)												
Y	1.00												
N	0.86	1.00											
L	0.93	0.90	1.00										
K	0.88	0.89	0.90	1.00									
K_1	0.87	0.82	0.90	0.91	1.00								
K_2	0.84	0.89	0.88	0.98	0.90	1.00							
B	0.58	0.70	0.62	0.76	0.55	0.83	1.00						
F	0.58	0.51	0.58	0.67	0.58	0.56	0.35	1.00					
wN	0.84	0.96	0.88	0.85	0.78	0.85	0.68	0.50	1.00				
T	0.91	0.87	0.93	0.87	0.84	0.85	0.62	0.55	0.85	1.00			
w											1.00		
t												1.00	
C	0.92	0.94	0.95	0.96	0.90	0.95	0.72	0.61	0.93	0.96			1.00

Note: For definition of the variables see Chapter III.

APPENDIX IV

ADDITIONAL REGRESSION RESULTS

TABLE IV.1

ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA

Year	No. of observations	Inter-cept	Coefficient of T	Coefficient of wN	Coefficient of K_2	Coefficient of F ratio	R^2	SEE a/	Sum of coefficients	F b/ ratio
1967/68	105	-2.359 (0.174)	0.493 (0.083)	0.128 (0.076)	0.359 (0.095)	0.071 (0.044)	0.946	0.384	1.050	3.71
1968/69	136	-2.560 (0.284)	0.417 (0.083)	0.119 (0.104)	0.239 (0.117)	0.126 (0.034)	0.870	0.413	0.952	0.22
1969/70	237	-3.058 (0.181)	0.582 (0.049)	0.179 (0.048)	0.194 (0.048)	0.052 (0.018)	0.876	0.325	1.007	0.40
1970/71	128	-2.761 (0.194)	0.409 (0.053)	0.292 (0.060)	0.133 (0.059)	0.094 (0.029)	0.936	0.231	0.983	0.43

Note: Equations linear in logarithms are estimated by least squares.
Dependent variable is output of wheat in physical units. T, wN, K_2 and F are total land rent, labor bill, capital costs and fertilizer costs respectively.
Standard errors of coefficients are in parentheses.
a/Standard errors of estimate are in natural logarithms of wheat output measured in quintals.
b/The calculated F-ratio is for testing the hypothesis of constant returns to scale.

R^2 is the coefficient of determination adjusted for degrees of freedom.

TABLE IV.2

ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA

Year	No. of observations	Intercept	Coefficient of T	Coefficient of wN	Coefficient of K	R^2	SEE[a/]	Sum of coefficients	F[b/] ratio
1967/68	105	-3.143 (0.224)	0.487 (0.086)	0.132 (0.077)	0.440 (0.116)	0.945	0.386	1.059	5.00
1968/69	136	-3.087 (0.270)	0.380 (0.086)	0.097 (0.106)	0.500 (0.123)	0.867	0.418	0.977	0.41
1969/70	287	-3.235 (0.176)	0.550 (0.049)	0.160 (0.047)	0.298 (0.043)	0.879	0.321	1.010	0.18
1970/71	128	-3.058 (0.192)	0.387 (0.054)	0.267 (0.059)	0.339 (0.067)	0.938	0.994	0.994	0.05

Note: Equations linear in logarithms are estimated by the least squares.
Dependent variable is output of wheat in physical units. T, wN and K are total land rent, labor bill and capital costs respectively.
Standard errors of coefficients are in parentheses.
a/Standard errors of estimate are in natural logarithms of wheat output measured in quintals.
b/The calculated F-ratio is for testing the hypothesis of constant returns to scale.

R^2 is the coefficient of determination adjusted for degrees of freedom.

APPENDIX V

SIZE DISTRIBUTION OF SAMPLE FARMS

TABLE V.1

SIZE DISTRIBUTION OF SAMPLE FARMS

Group Interval	Mean group size (acres)	Number of farms in the group	Percent of farms in the group	Cumulative percentage
0 < S ≤ 2.5	1.22	89	13.57	13.57
2.5 < S ≤ 5.0	3.68	99	15.09	28.66
5.0 < S ≤ 7.5	5.99	83	12.65	41.31
7.5 < S ≤ 10.0	8.68	61	9.30	50.61
10.0 < S ≤ 12.5	11.03	51	7.78	58.39
12.5 < S ≤ 15.0	13.84	57	8.69	67.08
15.0 < S ≤ 17.5	16.09	47	7.16	74.24
17.5 < S ≤ 20.0	18.64	43	6.56	80.80
20.0 < S ≤ 22.5	21.33	29	4.42	85.22
22.5 < S ≤ 25.0	23.50	16	2.44	87.66
25.0 < S ≤ 27.5	26.35	21	3.20	90.86
27.5 < S ≤ 30.0	28.65	7	1.07	91.93
30.0 < S ≤ 32.5	31.34	8	1.22	93.15
32.5 < S ≤ 35.0	33.87	4	0.61	93.76
35.0 < S ≤ 37.5	36.20	9	1.37	95.13
37.5 < S ≤ 40.0	38.10	5	0.76	95.89
40.0 < S ≤ 42.5	40.77	3	0.46	96.35
42.5 < S ≤ 45.0	43.84	1	0.15	96.50
45.0 < S ≤ 47.5	45.93	8	1.22	97.72
47.5 < S ≤ 50.0	48.60	2	0.30	98.02
50.0 < S ≤ 52.5	50.50	1	0.15	98.17
52.5 < S ≤ 55.0	53.65	4	0.61	98.78
55.0 < S ≤ 57.5	55.75	4	0.61	99.39
57.5 < S ≤ 60.0		0	0.0	99.39
60.0 < S ≤ 62.5	61.00	1	0.15	99.54
62.5 < S ≤ 65.0	64.11	3	0.46	100.00
0 < S ≤ 65.0	12.85	656	100.00	

NOTE: S stands for farm size measured in acres

Source: See Table 3.2 in Chapter III for a detail of farms in this sample.

BIBLIOGRAPHY

Abel, Martin E., "The Distribution of Agricultural Development Gains in India: A Case Study for South and Southeast Asia," Staff Paper P71-25, Dept. of Agricultural and Applied Economics, University of Minnesota, Nov 1971. To be published in Externalities in the Transformation of Agriculture: The Distribution of Benefits and Costs from Development (Iowa State University, forthcoming).

_______, "The Technological Component of Agricultural Development," Staff Paper P69-4, Dept. of Agricultural and Applied Economics, University of Minnesota, March 1969.

Adelman, J. and G. Dalton, "A Factor Analysis of Modernization in Village India," Econ. J., 81:563-579, Sept. 1971.

Agarwala, R., "Size of Holdings and Productivity: A Comment," Econ. Weekly 6:643-645, April 11, 1964.

_______, "Size of Holdings and Productivity: Further Comments," Econ. Weekly 6:1849-51, November 21, 1964.

Aigner, D. J. and S. F. Chu, "On Estimating the Industry Production Function," Am. Econ. Rev., 58:826-839, September 1968.

Allen, R. G. D., Mathematical Analysis for Economists, (New York: St. Martin's Press, Inc., Reprinted 1967).

Bachman, Kenneth L. and Raymond P. Christensen, "The Economics of Farm Size," in Agricultural Development and Economic Growth ed. Herman M. Southworth and Bruce F. Johnston (Ithaca: Cornell University Press, Ithaca, New York, 1967).

Bardhan, Kalpana, "Size of Holdings and Productivity: Further Comment," Economic Weekly 6:1401-1402, August 1964.

Bardhan, Pranab K., "Size, Productivity and Returns to Scale: An Analysis of Farm-Level Data in Indian Agriculture," an unpublished paper, 1972.

_______, "Green Revolution and Agricultural Labourers," Economic Weekly, Special Number, July 1970.

Barker, Randolph, "Green Revolution," Current Affairs Bulletin, January 1970.

Bean, Louis H., Second Report on Weather and Crop Relationships in India and the Feasibility of Forecasting, (New Delhi: U.S. Agency for International Development, American Embassy, New Delhi - 11, India, January 1970, mimeographed).

Ben-David, Shaul and William G. Tomek, "Allowing for Slope and Intercept Changes in Regression Analysis," A.E.Res. 179, Nov. 1965, Dept. of Agricultural Economics, Cornell University, Ithaca, New York.

Bennett, R. L., "Surplus Agricultural Labor and Development--Facts and Theories: Comment," Am. Econ. Rev., 57:194-202, March 1967.

Bhagwati, J. S. and S. Chakravarty, "Contributions to Indian Economic Analysis: A Survey," Am. Econ. Rev., 59:1-73, September 1969 (Supplement).

Billings, Martin H. and Arjan Singh, "The Effect of Technology on Farm Employment in India," Development Digest 9:98-107, January 1971.

_______, "Conventional Energy as a Constraint to the Green Revolution 1964-84: The Punjab Case," mimeo for USAID, New Delhi, April 1969.

Brar, G. S. and H. S. Sandhu, "Adjust Your Production to Flat Rate of Electric Charges," Progressive Farming, 1969.

Bronfenbrenner, M., "Production Functions: Cobb-Douglas, Interfirm, Intrafirm," Econometrica, 12:35-44, January 1944.

Brown, Murray, On the Theory and Measurement of Technological Change, (Cambridge, The University Press, 1968).

Brundy, James M. and Dale W. Jorgenson, "Efficient Estimation of Simultaneous Equations by Instrumental Variables," Rev. Econ. Stat. LIII:207-224, August 1971.

Carson, Sune, A Study on the Pure Theory of Production, (London: Stockholm Economic Studies, No. 9, P.S. King and Staples, Ltd., London, 1939).

Chaudhari, Dharam Pal, "Farmers Education and Productivity: Some Empirical Results from Indian Agriculture," Dept. of Econ. Human Capital Paper 69:4, University of Chicago, 1969.

Chennareddy, V., "Production Efficiency in South Indian Agriculture," J. Farm Econ. 49:816-820, Nov. 1967.

Chenery, Hollis B., "Overcapacity and the Acceleration Principle," Econometrica 20:1-28, January 1952.

Chow, Gregory C., "Tests of Equality Between Sets of Coefficients in Two Linear Regressions," Econometrica 28:591-605, July 1960.

Cochrane, Willard W. The World Food Problem, A Gaurdedly Optimistic View, (New York: Thomas Y. Crowell Company, Inc., 1969).

Dalrymple, Dana G., "Trends in Grain Area and Yield in Developed and Developing Nations," Am. J. Agr. Econ. 52:448-449, August 1970.

______, Imports and Plantings of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations, USDA FAS, November 1969.

Dillon, John L. and J. R. Anderson, "Allocative Efficiency, Traditional Agriculture and Risk," Am. J. Agr. Econ., 53:26-32, February 1971.

Directorate of Economics and Statistics, "Studies in Economics of Farm Management, Ferozepur District (Punjab)--Part II Tables," Ministry of Food and Agriculture, Government of India, 1967-68, 1968-69.

Dixit, R. S. and P. P. Singh, "Impact of High Yielding Varieties on Human Labour Input," Agricultural Situation in India, March 1970, pp. 1081-1089.

Domar, E., "On Total Productivity and All That," J. Pol. Econ., 70:597-608, December 1962.

Eckert, Jerry Bruce, "The Impact of Dwarf Wheats on Resource Productivity in West Pakistan's Punjab," an unpublished Ph.D. Thesis, Michigan State University, 1970.

Economic Adviser to Government, Punjab, Statistical Abstract of Punjab, 1970, Economic and Statistical Organization, Publication No. 114, Chandigarh, India, January 1971.

Falcon, Walter P., "The Green Revolution: Generations of Problems," Am. J. Agr. Econ. 52:698-722, December 1970.

Farrell, M. J., "The Measurement of Productive Efficiency," J. Royal Stat. Soc. (Series A), 120:253-281, 1957.

Floyd, John, "The Effects of Farm Price Supports on the Returns to Land and Labor in Agriculture," J. Farm Econ. 47:148-149, April 1965.

Foote, R. J., Analytical Tools for Studying Demand and Price Structures, (Washington: USDA Agr. Handbook 146, Washington D.C., August 1958.

Giles, G. W., "Agricultural Power and Equipment," in The World Food Problem, A Report of the President's Science Advisory Committee, Washington, September 1967, Vol. III.

Gill, K. S., Wheat Market Behaviour, Punjab and Haryana, 1968-69 to 1970-71 (Ludhiana: Department of Economics and Sociology, Punjab Agricultural University, Ludhiana, India, 1971).

Gill, Khem Singh, "The New Varieties of Wheat and Their Economics," a paper presented at the Summer Institute in Agricultural Finance, June-July 1970 at Punjab Agricultural University, Ludhiana, India.

Gotsch, Carl H., "Technical Change and Distribution of Income in Rural Areas," Am. J. Agr. Econ., 54:326-341, May 1972.

Gough, James W., "Agricultural Wages in Punjab and Haryana, A Note," Econ. and Pol. Weekly, Rev. of Agr: A-19, A-20, March 1971.

Griliches, Zvi, "Specification Bias in Estimates of Production Functions," J. Farm. Econ. 39:8-20, February 1957.

_______, "Demand for Fertilizer: An Economic Interpretation of Technical Change," J. Farm Econ. 40:591-606, August 1958.

_______, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," J. Pol. Econ. 66:419-431, October 1958.

_______, "The Demand for Inputs in Agriculture and a Derived Supply Elasticity," J. Farm. Econ., 41:309-322, May 1959.

_______, "Estimates of the Aggregate Agricultural Production Function from Cross-Sectional Data," J. Farm. Econ., 45:419-432, May 1963.

_______, "Sources of Measured Productivity Growth: United States Agriculture, 1940-60," J. Pol. Econ., 71:331-46, August 1963.

_______, "Research Expenditure, Education and the Aggregate Agricultural Production Function," Am. Econ. Rev. 54:961-974, December 1964.

_______, "Production Functions in Manufacturing: Some Preliminary Results," in The Theory and Empirical Analysis of Production, ed. Murray Brown, NBER Studies in Income and Wealth, Vol. 31, New York, 1967.

Haavelmo, Trygve, "The Statistical Implications of a System of Simultaneous Equations," Econometrica 11:1-12, January 1943.

Hall, M. L. and C. B. Winsten, "The Ambiguous Notion of Efficiency," Econ. J., 69:71-86, March 1959.

Harberger, Arnold C., "Investment in Man Versus Investment in Machines: The Case of India," in Education and Economic Development, ed. C. Arnold Anderson and Mary Jean Bowman, Chicago, Aldine, 1965.

Hayami, Yujiro, "Sources of Agricultural Productivity Gap Among Selected Countries," Am. J. Agr. Econ., 51:564-575, August 1969.

_______, "On the Use of the Cobb-Douglas Production Function on the Cross-Country Analysis of Agricultural Production," Am. J. Agr. Econ., 52:327-329, May 1970.

_______, and Vernon W. Ruttan, Agricultural Development: An International Perspective (Baltimore: The Johns Hopkins Press, 1971).

_______, "Elements of Induced Innovation: A Historical Perspective for the Green Revolution," Explanations in Economic History, 8:445-472, Summer/1971.

Heady, Earl O., "Optimal Sizes of Farms Under Varying Tenure Forms, Including Renting, Ownership, State and Collective Structures," Am. J. Agr. Econ., 53:17-25, February 1971.

_______, Economics of Agricultural Production and Resource Use, (Prentice Hall, Inc., Englewood Cliffs: 1964).

_______, "Uses and Concepts in Supply," in Agricultural Supply Functions, ed. Earl O. Heady, et. al. (Ames: Iowa State University Press, 1961).

_______, and Martin H. Yeh, "National and Regional Demand Functions for Fertilizer," J. Farm. Econ., Vol. XLI:332-348, May 1959.

_______, and John L. Dillon, Agricultural Production Functions (Ames: Iowa State University Press, 1966).

Henderson, James M. and Richard E. Quandt, Microeconomic Theory: A Mathematical Approach, Second edition, (New York: McGraw Hill Book Company, 1971).

Herdt, Robert W. and Willard W. Cochrane, "Farm Land Prices and Farm Technological Advance," J. Farm. Econ., 48:243-263, May 1966.

Herdt, Robert W., "A Disaggregate Approach to Aggregate Supply," Am. J. Agri. Econ., 52:512-520, November 1970.

_______, "An Analysis of the Aggregate Supply Function of Agriculture in the Punjab (India)," unpublished Ph.D. thesis, University of Minnesota, 1969.

_______, "Resource Productivity in Indian Agriculture," Am. J. Agr. Econ., 53:517-521, August 1971.

Hoch, Irving, "Estimation of Production Function Parameters and Testing for Efficiency," Econometrica 23:325-326, July 1955.

______, "Simultaneous Equation Bias in the Context of the Cobb-Douglas Production Function," Econometrica 26:566-578, October 1958.

Hopper, David W., "Allocation Efficiency in a Traditional Agriculture," J. Farm. Econ., 47:611-624, August 1965.

Hsieh, S. C. and V. W. Ruttan, "Environmental, Technological, and Institutional Factors in the Growth of Rice Production: Philippines, Thailand, and Taiwan," Food Research Institute Studies, 7:307-341, 1967, (Stanford: Stanford University, California).

Huang, Yukon, "Allocation Efficiency in a Developing Agricultural Economy in Malaya," Am. J. Agr. Econ., 53:514-516, August 1971.

Islam, Nurul, "Agricultural Growth in Pakistan: Problems and Policies," paper presented at the Conference on Agriculture and Economic Development, Tokyo and Hakone, September 6-10, 1971, (The Japan Economic Center).

Johl, S. S., Green Revolution in the Punjab, unpublished draft, Punjab Agricultural University, Ludhiana, India, 1970.

______, "Mechanization, Labor Use and Productivity in Agriculture," unpublished draft paper, Ohio State University, 1971.

______, Farm Size, Economic Efficiency and Social Justice, Punjab Agricultural University Press, Ludhiana, April 1972.

______ and H. S. Sandhu, Existing and Suggested Cropping Pattern by Type of Farming Areas, 1969-70, Department of Economics and Sociology, Punjab Agricultural University, Ludhiana, India, 1970. (Mimeographed).

Johnson, Paul R., "Some Aspects of Estimating Statistical Cost Functions," J. Farm. Econ., 46:179-187, February 1964.

______, "Discussion: A Test of the Hypothesis of Economic Rationality in a Less-Developed Economy," Am. J. Agr. Econ., 50:398-399, May 1968.

______, "On Testing Competing Hypotheses: Economic Rationality Versus Traditional Behavior: Reply," Am. J. Agr. Econ., 51:208-209, February 1969.

Johnston, J., Statistical Cost Analysis, (New York: McGraw-Hill Book Company, Inc., New York, 1960.

______, Econometric Methods, (New York: McGraw-Hill Book Company, Inc., 1963).

Johnston, Bruce F. and John Cownie, "The Seed Fertilizer Revolution and Labor Force Absorption," American Economic Review, LIX:569-582, Sept. 1969.

Kahlon, A. S. and J. L. Kaul, "Comparative Study of Economics of High-Yielding Varieties of Wheat, Punjab State," Indian J. Agr. Econ., 23:79-86, Oct.-Dec., 1968.

Kahlon, A. S., S. S. Miglani and S. K. Mahta, "Studies in Economics of Farm Management, Ferozepur District, Punjab - Report for 1968-69," Department of Economics and Sociology, Punjab Agricultural University Ludhiana, Punjab, India.

Kahlon, A. S. and S. S. Grewal, "Farm Mechanization in Labor-Abundant Economy, A Comment," Econ. and Pol. Weekly, May 13, 1972.

Kaneda, Hiromitsu, "Economic Implications of the 'Green Revolution' and the Strategy of Agricultural Development in West Pakistan," Pakistan Development Review, 9:111-143, Summer 1969.

Khusro, A. M., "Returns to Scale in Indian Agriculture," Indian J. Agr. Econ., 19:51-80, October 1964.

_______, "Structural Change in Indian Agriculture," paper presented at the Conference on Agriculture and Economic Development, Tokyo and Hakone, September 6-10, 1971, (The Japan Economic Research Center.)

Klein, L. R., A Textbook of Econometrics (Evanston: Row Peterson, 1953).

Kmenta, J., "On Estimation of the CES Production Function," Social Systems Research Institute, University of Wisconsin, Paper No. 6410, October, 1964.

_______, "On Estimation of the CES Production Functions," International Econ. Rev., Vol. VIII, June 1967.

Krishna, Raj, "Agricultural Price Policy and Economic Development," in Agricultural Development and Economic Growth, ed. Herman M. Southworth and Bruce F. Johnston (Ithaca: Cornell University Press, Ithaca, New York, 1967).

_______, "New Technology, Food Production and Equity," A paper presented at the Symposium on Food Production and Income Distribution in South Asia--The Double Dilemma, Kansas State University, Manhattan, Kansas, September 1969.

Ladejinsky, Wolf, "The Green Revolution in Punjab: A Field Trip," Econ. and Pol. Weekly, Rev. of Agri: A73-A82, June 1969.

Lau, L. J., "Some Applications of Profit Functions," Memorandum Nos. 86A and 86B, Research Center in Economic Growth, Stanford University, November 1969.

_______, "Profit Functions of Technologies with Multiple Inputs and Outputs," Memorandum No. 116, Research Center in Economic Growth, Stanford University, September 1971.

_______ and P. A. Yotopoulos, "A Test for Relative Economic Efficiency and Application to Indian Agriculture," Am. Econ. Rev., 61:94-109, March 1971.

_______, "Profit, Supply, and Factor Demand Functions," Am. J. Agr. Econ., 54:11-18, Feb. 1972.

_______, "A Test for Relative Economic Efficiency: Some Further Results," Memorandum No. 104, Research Center in Economic Growth, Stanford University, Aug. 1970.

_______, "Micro-functions in Macro-Model: An Application to Agricultural Employment and Development Strategies," Memorandum No. 108, Research Center in Economic Growth, Stanford University, February 1971.

Lawrence, Roger, "Some Economic Aspects of Farm Mechanization in Pakistan," Aug. 1970, unpublished.

Leibenstein, Harvey, "Notes on X-Efficiency and Technical Progress," Harvard Institute of Economic Research, Discussion Paper No. 162, Harvard University, Cambridge, Massachusetts, January 1971.

Lockwood, Brian, P. K. Mukerjee and R. T. Shand, "The High Yielding Varieties Program in India," Part 1, mimeo, Australian National University, 1971.

Lydall, H., "A Theory of Distrubition and Growth with Economies of Scale," Econ. J., 81:91-112, March 1971.

Madden, Patrick J., Economies of Size in Farming. Agricultural Economics Report No. 107, Economic Research Service, U.S. Dept. of Agriculture, Feb. 1967.

Marschak, Jacob and William H. Andrews, Jr., "Random Simultaneous Equations and the Theory of Production," Econometrica, 12:143-205, July-October, 1944.

Mazumdar, Dipak, "On the Economics of Relative Efficiency of Small Farmers," Econ. Weekly, 5:1212-24, Special No., July 1963.

_______, "Size of Farm and Productivity: A Problem of Indian Peasant Agriculture," Economica, 32:161-173, May 1965.

Mellor, John W., "The Functions of Agricultural Prices in Economic Development," Indian J. Agr. Econ., 23:21-37, January-March 1968.

_______, "Agricultural Price Policy in the Context of Economic Development," Am. J. Agr. Econ., 51:1413-1420, December 1969.

Mononey, John R., "Economies of Scale in Manufacturing," in Price Theory in Action, ed. Donald Stevenson Watson, (Boston: Houghton Mifflin Company, 1969).

Mundlak, Yair, "Empirical Production Function Free of Management Bias," J. Farm. Econ., 43:44-56, February 1961.

_______, "Specification and Estimation of Multiproduct Production Functions," J. Farm. Econ., 45:433-445, May 1963.

_______ and Irving Hoch, "Consequences of Alternative Specifications in Estimation of Cobb-Douglas Production Functions," Econometrica 3:814-828, October 1965.

Myrdal, Gunnar. Asian Drama: An Inquiry Into the Poverty of Nations. New York: Twentieth Century Fund, 1968.

Nadiri, M. Ishang, and Sherwin Rosen, "Interrelated Factor Demand Functions," Amer. Econ. Rev., LIX:457-471, September 1969.

Nerlove, M., Estimation and Identification of Cobb-Douglas Production Functions (Chicago: Rand McNally and Company, 1965).

_______, "Recent Empirical Studies of the CES and Related Production Functions," in The Theory and Empirical Analysis of Production, ed. Murray Brown, NBER Studies in Income and Wealth, Vol. 31, New York, Columbia University Press, 1967, pp. 55-136.

Oommen, T. K., "Green Revolution and Agrarian Conflict," Econ. and Pol. Weekly, Rev. of Agr., A99-A103, June 1971.

Paddock, W. and P. Paddock. Famine, 1975 (New York: Little, Brown and Co., 1967).

Paglin, Morton, "Surplus Agricultural Labor and Development: Facts and Theories," Am. Econ. Rev., 55:815-834, Sept. 1965.

_______, "Surplus Agricultural Labor and Development--Facts and Theories: Reply," Am. Econ. Rev., 57:202-209, March 1967.

Pathak, B. S., "Some Problems of Mechanization of Agriculture in Punjab," Study No. 2, Punjab Agricultural University, May 1970.

Phillips, Richard, "Discussion: Inducing Economic Development to Less Developed Countries," Am. J. Agr. Econ., 51:1424-1426, Dec. 1969.

Punjab Agricultural University, Wheat Cultivation in Punjab, a draft for a bulletin by the Department of Agronomy, Punjab Agricultural University, Ludhiana, India, 1971.

Punjab Agricultural University, Ludhiana (India), Package Practices for Rabi Crops of Punjab and Himachal Pradesh, 1970-71, Directorate of Extension Education, October 1970.

Punjab Agricultural University, Punjab Agricultural Handbooks, 1970, 1971, Department of Information and Communication, Punjab Agricultural University, Ludhiana, India.

Ralph, D. Wennbolm and Glen Lorang, "Shorter Wheats for Everybody," Farm Journal, pp. 16-67, 27-28, July 1969.

Rani, Usha, "Size of Farm and Productivity," Econ. and Pol. Weekly, Rev. of Agr. A85-A89, June 1971.

Rao, C. H. Hanumantha, Agricultural Production Functions, Costs and Returns in India, Institute of Economic Growth Series No. 5, (Bombay: Asia Publishing House, 1965).

_______, "Farm Size and Economies of Scale," Econ. Weekly, Dec. 14, 1963.

_______, "Alternative Explanations of the Inverse Relationship between Farm Size and Output per Acre in India," Indian Econ. Rev., Oct. 1966.

_______, "Farm Mechanization in a Labor-Abundant Economy," Econ. and Pol. Weekly, Annual Number, Feb. 1972.

_______, "Investment in Farm Tractors in India: Private Versus Social Costs and Benefits," Unpublished, 1972.

Raychaudhari, S. P. et. al., Soils of India, Indian Council of Agricultural Research, New Delhi, 1963.

Registrar General and Census Commissioner, Provisional Population Totals, Census of India, 1971, Series 1, Paper 1 of 1971, Supplement.

Roberts, William and S. B. S. Kartar Singh, A Textbook of Punjab Agriculture, (Lahore: Civil and Military Gazette, 1947).

Rudra, Ashok, "Farm Size and Yield Per Acre," Econ. and Pol. Weekly, Special Number, July 1968.

_______, "More on Returns to Scale in Indian Agriculture," Econ. and Pol. Weekly, October 1968.

_______, "Employment Patterns in Large Farms of Punjab," Econ. and Pol. Weekly, Rev. of Agr. A89-A94, June 1971.

Rudra, A., A. Majid, and B. D. Talib, "Big Farmers of Punjab: Some Preliminary Findings of a Sample Survey," Econ. and Pol. Weekly, Rev. of Agr. 4: September 1969.

Ruttan, Vernon W., "Perspective on the 'Green Revolution' in Asia," Staff Paper P71-30, Dept. pf Agr. and Applied Economics, University of Minnesota, December, 1971.

Sadan, Ezra, "Partial Production Functions and the Analysis of Farm-Firm Costs and Efficiency," Am. J. Agr. Econ., 52:62-70, February 1970.

Sahota, G. S., "Efficiency of Resource Allocation in Indian Agriculture," Am. J. Agr. Econ., 50:584-605, August 1968.

Saini, G. R., "Farm Size, Productivity and Returns to Scale," Econ. and Pol. Weekly IV, No. 26: A119-A122, June 1969.

_______, "Holding Size Productivity, and Some Related Aspects of Indian Agriculture," Econ. and Pol. Weekly, Rev. of Agr.: A79-A85, June 1971.

Sandhu, H. S. and Raghbir Singh, "Economics of Alternative Choices in Selected Improved Practices of General Crop Farms in Ludhiana District," J. Research, 6:511-523, June 1963. (Supplement) A Publication of the Punjab Agricultural University, Ludhiana, India.

Sanyal, S. K., "Size of Holding and Some Factors Related to Production," Econ. and Pol. Weekly, IV, No. 33:1345-1347, August 1969.

Schluter, Michael, "Differential Rates of Adoption of the New Seed Varieties in India: The Problem of Small Farm," Occasional Paper No. 47, Dept. of Agr. Econ., Cornell University, August 1971.

Schmitz, Andrew and David Seckler, "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester," Am. J. Agr. Econ., 52:569-577, November 1970.

Schultz, Theodore W., Transforming Traditional Agriculture. (New Haven: Yale University Press, 1964).

_______, "A Framework for Land Economics--The Long View," J. Farm. Econ., 33:204-215, May 1951.

_______, "Diminishing Returns in View of Progress in Agricultural Production," J. Farm. Econ., 24:640-649, October 1932.

Sehgal, Jawaharl, C. Sys and D. R. Bhumbla, "A Climatic Soil Sequence from the Thar Desert to the Himalayan Mountains in Punjab India," Pedologie, 18:351-373, 3 Fig. Fhent, 1968.

Seitz, Wesley D., "The Measurement of Efficiency Relative to a Frontier Production Function," Am. J. Agr. Econ., 52:505-511, November 1970.

Sen, Amartya K., "An Aspect of Indian Agriculture," Econ. Weekly, 4:107-112, Annual No., January 1962.

_______, "Peasant and Dualism with or without Surplus Labor," J. Pol. Econ., 74:425-450, October 1968.

_______, "A Reply," Econ. Weekly, 6:872-874, May 2, 1964.

_______, "Size of Holdings and Productivity," Econ. Weekly, 6:57-61, Annual No., February 1964.

Sethuraman, S. V., "Long Run Demand for Draft Annimals in Indian Agriculture," An unpublished Ph.D. thesis, The University of Chicago, March 1970.

Shaw, Robert d'A. Jobs and Agricultural Development (Washington, D.C.: Overseas Development Council, 1970), Monograph No. 3.

Shephard, R. W., Cost and Production Functions, (Princeton: Princeton University Press, 1953).

Singh, I. J., "Tubewell Irrigation in the Punjab," Studies in Agricultural Capital and Technology, Occasional Paper No. 17 of the Dept. of Agricultural Economics and Rural Sociology, Ohio State University, November 1970.

_______ and K. C. Sharma, "Response of Some Mexican Red and Indian Amber Wheats to Nitrogen," Indian J. Agr. Econ., 23:86-93, October-December 1968.

_______, Richard H. Day and S. S. Johl, Field Crop Technology in the Punjab, India (Madison: Social Systems Research Institute, University of Wisconsin, Madison, Wisconsin, 1968).

_______, "A Recursive Programming Model of Traditional Agriculture in Transition," Ph.D. Thesis, University of Wisconsin 1971.

Srinivasan, T. N., "Farm Size and Productivity: Implications for Choice Under Uncertainty," Discussion Paper No. 53, Planning Unit, Indian Statistical Institute, January 1971.

Staehle, Hans, "The Measurement of Statistical Cost Functions: An Appraisal of Some Recent Contributions," in Readings in Price Theory, (Chicago: Richard D. Irwin, Inc., 1952), pp. 264-282.

Stigler, George J., The Theory of Price (New York: The Macmillan Company, 1966).

Suits, Daniel B., "Use of Dummy Variables in Regression Equations," J. Am. Stat. Assoc., 52:548-551, December 1957.

Theil, Henri, Principles of Econometrics (New York: John Wiley and Sons, Inc., 1971).

Timmer, C. P., "Using a Probabilistic Frontier Production Function to Measure Technical Efficiency," J. Pol. Econ., 79:776-794, July-August 1971.

Tintner, Gerhard, "A Note on the Derivation of Production Functions from Farm Records," Econometrica, 12:26-34, January 1944.

_______, "Significance Tests in Production Function Research," in Resource Productivity, Returns to Scale, and Farm Size, ed. Earl O. Heady, et. al., (Ames: The Iowa State College Press, Ames, Iowa, 1956).

Tomek, William G., "Using Zero-One Variables with Time Series Data in Regression Equations," J. Farm Econ., 45:814-822, Nov. 1963.

Ulveling, Edwin F. and Lehman B. Fletcher, "A Cobb-Douglas Production Function with Variable Returns to Scale," Am. J. Agr. Econ., 52:322-326, May 1970.

US AID, "New Serial Varieties, Rice and Wheat in India," Spring Review, Draft, March 1969, US AID, India.

Uzawa, H., "Duality Principles in the Theory of Cost and Production," International Econ. Rev., 5:216-220, May 1964.

Viner, Jacob, "Cost Curves and Supply Curves," in Reading in Price Theory, (Chicago: Richard D. Irwin, 1952), pp. 198-233.

Walters, A. A., "Production and Cost Functions: An Econometric Survey," Econometrica, 31:1-61, Jan. 1963.

Welch, F., "Education in Production," J. Pol. Econ., 78:35-59, Jan., Feb., 1970.

Wharton, Clifton R., "The Green Revolution: Cornucopia or Pandora's Box," Foreign Affairs, April 1969.

Wharton, Clifton R. Jr., "Research on Agricultural Development in South Asia," J. Farm Econ., 45:1161-1182, December 1963.

_______, "Risk, Uncertainty and the Subsistence Farming: Technological Innovation and Resistance to Change in the Context of Survival," A paper presented at the Joint Session of American Economic Association and Association for Comparative Economics, Chicago, Illinois, December 1968.

Willet, Joseph W., The Impact of New Grain Varieties in Asia, U. S. Dept. of Agr., ERS-Foreign 275, July 1969.

Williams, F. A., "Discussion: Agricultural Price Policy in the Context of Development," Am. J. Agr. Econ., 51:1420-1424, December 1969.

Wise, John and Pan A. Yotopoulos, "The Empirical Content of Economic Rationality: A Test for a Less Developed Economy," J. Pol. Econ., 77:976-1004, November-December 1969.

Yotopoulos, P. A., "From Stock to Flow Capital Inputs for Agricultural Production Functions: A Microanalytic Approach," J. Farm. Econ., 49:476-491, May 1967.

_______, "On the Efficiency of Resource Utilization in Subsistence Agriculture," Food Research Institute Studies in Agricultural Economics, Trade and Development, Vol. VIII, No. 2, 1968, Stanford University, Stanford, California.

_______, L. J. Lau, and K. Somel, "Labor Intensity and Relative Efficiency in Indian Agriculture," Food Research Institute Studies in Agricultural Economics, Trade and Development, 9:43-55, 1970.

Zellner, Arnold, "An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias," J. Am. Stat. Assoc. 57:348-375, June 1962.

_______, J. Kmenta, and J. Dreze, "Specification and Estimation of Cobb-Douglas Production Function Models," Econometrica, 34:784-795, October 1966.