PERFORMANCE ANALYSIS OF IRRIGATION SOURCES AND MAJOR IRRIGATED CROPS IN TAMIL NADU

Thesis submitted in part-fulfilment of the requirements for the degree of **Doctor of Philosophy** in Agricultural Economics to the Tamil Nadu Agricultural University, Coimbatore.

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CERTIFICATE

This is to certify that the thesis entitled **"PERFORMANCE ANALYSIS OF IRRIGATION SOURCES AND MAJOR IRRIGATED CROPS IN TAMIL NADU"**, submitted in part fulfilment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY IN AGRICULTURAL ECONOMICS** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **Thiru T.R.SHANMUGAM** under my supervision and guidance and that no part of thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles and that the work has not been published in part or full in any scientific or popular journals or magazines.

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T.R. Shanmugam

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INTRODUCTION

CHAPTER I

INTRODUCTION

The importance of water as a valuable resource for agriculture can never be over-emphasized. The increasing need for crop production for the growing population has necessitated rapid expansion of irrigation throughout the country. With the result, India has today the world's second largest irrigated area next to China. From 23.2 million hectares in 1951-52 which marked the beginning of planned development, the gross irrigated area in the country has gone upto 81 million hectares in 1989-90, registering about three fold increase during the past four decades (Table 1).

The major sources of irrigation in India are - tanks, canals and wells. Tanks have existed in India from time immemorial, and have been an important source of irrigation, particularly in South India. Nearly one third of rice in southern peninsular is irrigated by tanks. Large-scale canal irrigation, by contrast, began to develop about 100 years ago when capital investment in irrigation became feasible. The objective of canal irrigation projects in India has transformed from mere economic interest in the pre-independent era to achieving self

Table 1. Development of irrigation in India

Period	Outlays (Rs.in crores)			Cumulative potential created (m.ha)		
	Major& medium	Minor	Total	Major& medium	Minor	Total
Pre plan	..	..	..	9.70	12.90	22.60
First plan (1951-56)	300	76	456	12.20	14.06	26.26
Second plan (1956-61)	380	142	522	14.30	14.79	29.09
Third plan (1961-66)	581	328	909	16.60	17.01	33.61
Annual plans (1966-69)	434	326	760	18.10	19.00	37.10
Fourth plan (1969-74)	1237	513	1750	20.70	23.50	44.20
Fifth plan (1974-78)	2442	631	3073	24.82	27.30	52.12
Annual plans (1978-80)	2056	497	2553	26.60	30.00	56.60
Sixth plan (1980-85)	7516	1802	9318	30.50	37.40	67.90
Seventh plan (1985-90)	11556	2805	14361	34.80	46.00	80.80

Source : Government of India, Five Year Plan Documents, Planning Commission, New Delhi.

sufficiency in food production in the post-independent era. The development of well irrigation has mainly been linked to the development of new lifting power technology. With the introduction of small engines and the beginning of rural electrification, water lifting became simpler and cheaper, favouring well irrigation development in the country.

Irrigation Development in India

The total investment in irrigation from the beginning of the planning era in 1951 to the end of Seventh Plan period amounted to approximately Rs.143.61 billions on major, medium and minor projects. Minor irrigation has contributed over half of the growth in total irrigation potential (Table 1).

The absolute growth in the irrigation sector has been, on average, 2.1 million hectares per year during the Sixth Plan and 2.6 million hectares per year during the Seventh Plan period, with one third of this area going to major and medium irrigation projects and the rest to minor irrigation projects.

In the case of minor irrigation projects, particularly wells, private investment has contributed more, as majority of the wells are owned by individuals. Of the nine million wells in India, public wells account for only less than one per cent. Several factors are responsible for the rapid development of groundwater in the post-green revolution period. The introduction of high yielding varieties in the late sixties caused a rapid development of tubewells, especially in the northern and southern regions. At the same time, institutional credit for minor irrigation began to grow rapidly. During the planning period, it grew at a rate of 6.4 per cent per year significantly higher than the growth rate of total public and private expenditure on irrigation (2.8 per cent per year). The Agricultural Refinance and Development Corporation (ARDC) has played an important role in providing this type of credit. The spread of electricity to rural areas in the last few decades has stimulated investment in the relatively less expensive electric pumpsets, the growth rate of which has been around 3.0 per cent. During 1979-80, the Rural Electrification Corporation (REC) was created to provide special finance for electrification of groundwater pumping.

Growth rates of irrigated area for the period 1951-90 and for the two periods, 1951-65 and 1966-90 which correspond to before and after green revolution had indicated that the net irrigated area had expanded significantly over the four decades (2.3 per cent per year); the growth rate of net irrigated area during post- green revolution period has increased to 2.4 per cent per year from 1.7 per cent during pre-green revolution period. Among the individual sources of irrigation, area irrigated by wells had registered a higher growth rate of 4.1 per cent per year over the four decades and 4.6 per cent per year during the green revolution period, in particular. Area irrigated by canals has a steady growth rate over the entire period, i.e., 2.0 per cent per year. Area irrigated by tanks has shown a negative growth rate of 1.9 per cent per year during the green revolution period (1966-90) as compared to a negative growth rate of 0.5 per cent per year during the period, 1951-90 (Table 2).

Table 2. Growth rates of net irrigated area by sources in India

Variable	1951-1990	1951-1965	1966-1990
Net area irrigated	2.3	1.7	2.4
Canals	2.0	2.0	2.0
Wells	4.1	1.6	4.6
Tanks	-0.5	2.4	-1.9
Other sources	0.2	0.0	0.4

Source : Government of India, Five Year Plan Documents, Planning Commission, New Delhi.

The trends in complementary inputs, such as fertilizers and HYVs are related to trends in net irrigated area. Fertilizer and HYV use, which had growth rates of 9.9 per cent per year, and 14.5 per cent per year during pre green revolution and green revolution period, respectively, were closely related to the trend in irrigated area.

The Case of Tamil Nadu

The total annual rainfall run-off of Tamil Nadu is about 12.3 million hectare meter (mhm), of which, total water potential of the state has been assessed at 5.5 mhm comprising 2.5 mhm of surface water, 1.5 mhm of ground water and 1.5 mhm of water from other states as well as interbasin transfer. The demand for water for agricultural purposes in 2000 AD in Tamil Nadu would be 4.48 mhm as against the supply of 3.70 mhm.[1]

Canals, tanks and wells are the principal sources of irrigation in Tamil Nadu. During the five year plans, the government focussed mainly on major and medium surface irrigation projects and ground water development. The availability of favourable sites for reservoir construction

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[1] R.K.Sivanappan and K.Palanisami, Demand for Water in Tamil Nadu in 2000 AD - Future Focus and Policy Issues, Final Report, Tamil Nadu Agricultural University, Coimbatore, 1982.

and institutional finance accelerated the growth of major and medium projects. Energization, rural electrification and institutionalization of credit gave a boom to ground water development. However tank irrigation has been considered as neglected opportunity both by the government and the local community over years.

Canals and tanks which had accounted for more than one-third each in 1950s and 1960s, gradually got tilted in favour of wells which has emerged as major source in 1980s and 1990s. The share of canal irrigation has declined from 38 per cent in 1950s to 34 per cent in 1990s. The tank irrigation share has declined from 37 per cent in 1950s to 20 per cent in 1990s. The well irrigation share has increased from 24 per cent in 1950s to 45 per cent in 1990s which might be due to the importance given to minor irrigation schemes in the latter five year plans as well as by private investment by the farmers (Tamil Nadu - An Economic Appraisal, 1989).

The Problems

Though the area irrigated by wells move in the upward direction in the state, there has been a gradual decline in the tank irrigated area and stagnation in the case of canal irrigated area. Irriga.ed area over years might have responded much more to price policies complemented by other non-price measures such as irrigation investment, infrastructure, research and extension. Little efforts have been made in analysing the quantifying such variables both in the short run and long run perspectives of irrigation development in the state. Shrinkage in tank storage capacity and uncertain rainfall have reduced the tank water availability resulting in reduction in irrigated area and crop yield, besides increase in water stress. In several cases, the farmers started supplementing the inadequate tank water with ground water particularly at the later stage of the rice crop.[2]

Further, expansion of major irrigation projects are subjected to cost escalation with available capital, availability of potential site, longer gestation period and environmental implications.[3]

Ground water exploitation has a limited future owing to over exploitation in several locations, interrupted supply of electrical energy and erratic rainfall distribution.[4]

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[2] K. Palanisami and William K. Easter, "Irrigation Tanks of South India : Management Strategies and Investment Alternatives", **Indian Journal of Agricultural Economics**, 34 (2): 214-223, 1984.

[3] K.S. Satyajit, "Evaluating Large Dams in India", **Economic and Political Weekly**, 25 (11) : 142-143, 1990.

[4] M.G.Chandrakanth and Jeff Romm, "Ground Water Depletion in India - Institutional Management Regimes", **Natural Resources Journal**, 30 (4) : 485-501, 1990.

With respect to irrigation, one could witness ongoing and upcoming problems related to pattern of water resource development in Tamil Nadu over years. Sourcewise area allocation among irrigated crops are influenced by incentives, constraints, resources, environment and other related variables. It is important to keep in mind that crop pattern changes in canal and tank irrigation reflect decisions made by government and thus is exogenous to the individual farmer. On the other hand, expansion in area irrigated by wells largely reflects decisions made by farmers themselves. Although the decision to expand the sources are made by both private and public sectors, some of the factors affecting these decisions are similar. Productivity and economic efficiency of the major irrigated crops differ across the sources and they are influenced by technology and resources applied in the production process. Continued progress in water resources development in the future will depend upon the utilization of the existing irrigation potential by way of increasing cropping intensity, productivity and economic efficiency of major crops grown in these sources.

Hence future focus will be to identify and evaluate the factors associated with supply shift in different sources of irrigation and to find out the suitability of crops to be grown in a particular source in terms of area allocation, productivity and efficiency. Simultaneous consideration of all the sources as well as major crops grown in these sources is highly warranted.

Hypotheses

1. There exist some constraints, incentives, resources and environmental variables in the transformation of canal, tank and well irrigated agriculture in Tamil Nadu.

2. There exist inter-source differences in productivity and economic efficiency.

Objectives

The general objective is to study the factors influencing the performance of irrigation sources and major irrigated crops in Tamil Nadu. The specific objectives are:

i) to identify and determine the factors influencing the expansion of irrigated area by sources,

ii) to identify and analyse the factors explaining the allocation of irrigated area among major crops viz., rice, sugarcane, groundnut and cotton in each source, and

iii) to assess inter-source efficiency and determinants of economic efficiency in crop production.

Scope

It is felt that the results of the present study would be useful to the planners, administrators, scientists and water technologists of the state. Irrigation policy focusing on investment prioritization in the development of water sources could also be possible through the results of the study. It is also possible to identify priority crops under different systems based on productivity and economic efficiency. The study will also help to relax the investment disparities, if any, among development of different water sources.

Limitations

The present study suffers from the usual limitation of availability of data. As the study covers the entire state, some assumptions are made to avoid aggregation bias, as and when necessary. Moreover, the present study is based on secondary data and official documents, which have lacked consistency and uniformity over time. Necessary cleaning and standardisation of data have been done using the available information from scheme on Cost of Cultivation of Principal Crops (CCPC) and from National Sample Survey (NSS) data.

Organisation of the thesis

The study has been organised in the following pattern.

Chapter I	:	The problem focus, objectives, hypotheses, scope and limitations of the study are specified.
Chapter II	:	Review of past studies are documented.
Chapter III	:	Design of the study along with tools of analysis are explained.
Chapter IV	:	General characteristics of the study area are narrated.
Chapter V	:	Results and discussion are covered.
Chapter VI	:	Summary, findings of the study and policy implications are indicated.

CONCEPTS AND REVIEW

CHAPTER II

CONCEPTS AND REVIEW

Conceptualization is an essential part in any research study. Review of concepts used in earlier studies provide a link with past approaches and help one to adopt, modify and improve the present analytical framework. This chapter briefly reviews the concepts and literature pertaining to supply response models for irrigated crops and sources and measurement of economic efficiency.

The review of concepts have been organised under the following headings.

1. Supply response models
2 Economic efficiency

Supply response models

The literature on supply response models in agriculture has been mounting for the past three decades. The farmers' acreage response to price changes has been extensively studied for different crops across the country. However, efforts for further research in this area must continue because dynamic changes in the farm front due to irrigation, technology and institutional transformations warrant search for operationally relevant information for reorienting the existing policies to suit the changing environs. Sophisticated supply response models are constructed to move very close to real world situations.

A subtle distinction is made between traditional supply of economic theory and response relations. The term supply is to describe a specific type of relation. This specifies a price-quantity or price-area relation, when all other factors held constant. The response relation is more general concept, which describes what will happen to the quantity or area when other factors are not held constant. It is more of a study of the shifters of supply inclusive of irrigation, technology,and infrastrcture[1].

Diewert (1971) applied the generalised Leontief profit function to derive the output supply and input demand functions in the simultaneous framework. Percentage of area under irrigation was used as a technology shift variable. The estimation of supply as a function of prices, rather than inputs, eliminated the simultaneity bias. The profit function eliminated the problem of multicollinearity among

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[1]Williard W.Cochrane, "Conceptualizing the Supply Relation in Agriculture", Journal of Farm Economics, 37 (5) : 1161-1176, 1958.

the inputs and it had the theoretical and consistency properties of production technology.[2]

Labys (1973) applied dynamic supply models in explaining commodity supplies. The expansion of the dynamic relationship included a number of different shapes in the pattern of the distributed lags. He began with a Koyck lag which specified that output would be a function of distributed lag of past prices where the successive values of the lag coefficient declined geometrically. He also specified the Burrow's model as supply would be the function of present price, last year supply and exogenous factors. These two supply functions contained current price as a common variable. It was found that Koyck lag distribution model was preferable in several cases since each of the lagged price variables were taken separately and explained the commodity supply well.[3]

Shumway (1983) developed a dynamic supply response model in which the determinants of supply were the prices, investment and technology variables. He utilized the

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[2] W.E.Diewert, "An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function", **Journal of Political Economics**, 79(4): 481-507, 1971.

[3] Walter C.Labys, **Dynamic Commodity Models: Specification, Estimation and Simulation**, (London: D.C.Heath and Company, 1973).

applied duality theory to derive systems of output supply and factor demand equations from underlying profit functions. In this dual approach, output for each crop and total input use were determined simultaneously as a function of prices of each crop and each input, the fixed inputs representing technology, investment, environment and government policies. In this approach, changes in the optimal input and output combinations were not distinguished from the changes in the allocation of quasi-fixed inputs.[4]

Chand and Kaul (1986) used the Cobb-Douglas profit function to estimate the profit, output supply and input demand assuming the production process is of constant returns to scale. The profit, input demand and output supply functions were estimated simultaneously. Though the Cobb-Douglas profit function had been proved to have some weaknesses, it might be the easiest functional form to derive the input demand and output supply simultaneously.[5]

Bewley et al. (1987) used the area response model in allocating the planted area of all crops. The logic of the

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[4] C.R.Shumway, "Supply, Demand and Technology in a Multiproduct Industry: Texas Field Crops", **American Journal of Agricultural Economics**, 65(4):748-760, 1983.

[5] R.Chand and J.K.Kaul, "A Note on the Use of Cobb-Douglas Profit Function", **American Journal of Agricultural Economics**, 68(8): 1962-1964, 1986.

model was that the size of land allocated for the given crop depended on expected net revenue obtained from that crop, expected net revenue of the competitive crop, farming technologies, environment and scale of the land. The model would meet the condition that the sum of planted area of each crop would equate total area. It means that the predicted share of each crop would lie between zero and one and never be negative to estimate the area response.[6]

Dhawan (1988) estimated productivity by source of irrigation using single equation model. Multiple regression technique has been used on a cross-section district level data whereby the total crop output of a district was regressed on sourcewise irrigated area and rainfed acreage. Crop output was decomposed into four components viz., output on canal, tank, well and rainfed acreage. He applied the Ordinary Least Squares Method subject to the constraint that the regression plane passed through the origin as there was no constant term in the model. He cautioned that error might occur on three counts. First, sampling error might originate from the underlying yield estimates. Second misclassification of source would arise when two or three

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[6] R.Bewley, T.Young and D.Coleman, "A System Approach to Modelling Supply Equations", **Journal of Agricultural Economics**, 38(1):151-166, 1987.

sources were used to irrigate the same crop. Third, when cross section data were pooled for two or more years in order to enlarge the degrees of freedom for the regression estimates, each parameter might possess a cyclical component whose expected value over the agricultural cycle would be deemed to be zero.[7]

Tabor (1988) constructed an econometric model for Indonesia using a two step production approach. This approach characterised by a separate behavioural equations each for planted area, yield and input demand. This approach was based on the fact that the farmer decided the *input demand and hence the yield*. He used the translog profit functions to estimate the demand and supply of food crops.[8]

Huffman and Evenson (1989) modified the profit function approach to derive the total supply and total factor demand. They included the input variables in the model as the sources of change in the total supply. The sources were the technology, total input demand and the

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[7] B.D.Dhawan, "Methodology for Assessing Irrigation Impact", **Irrigation in India's Agricultural Development**, (New Delhi:Sage Publications India Private Limited, 1988).

[8] S.R.Tabor, Supply and Demand for Food Crops in Indonesia, Directorate General of Food Crops, Final Report, Ministry of Agriculture, Jakarta, 1988.

scale economies. The total factor index was constructed, incorporating all variable inputs by weighted mean.[9]

Chaudhry and Ali (1989) constructed simultaneous and simulation models to analyse the supply shift due to the cumulative effect of operation and maintenance expenditure on the canal irrigation system in Pakistan. Agricultural productivity index was constructed using production and prices of wheat, rice, cotton, maize and sugarcane crops. The productivity index was estimated as a function of operation and maintenance expenditure lagged over the past five years, gross domestic product deflated, technology and the parity price ratio. However, the operation and maintenance expenditure was considered as the supply shifter in the simulation model. The annual growth in the productivity index between two time periods was considered as supply shift. They have found that the cumulative amount spent on operation and maintenance of canal irrigation would shift the supply upward.[10]

Rosegrant and Pasandaran (1990) developed an irrigation investment model for Indonesia. The variables

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[9] W.E.Huffman and R.E.Evenson, "Supply and Demand Functions for Multiproduct United States Cash Grain Farms : Biases caused by Research and other Policies", **American Journal of Agricultural Economics**, 71(3):761-773, 1989.

[10] M.A.Chaudhry and Mubarik Ali, "Measuring Benefits to Operation and Maintenance Expenditure in the Canal Irrigation System of Pakistan : A Simulation Analysis", **Agricultural Economics**, 3(1): 199-212, 1989.

tested in alternative regression specifications of the irrigation investment model which affected the profitability of irrigation were: the real World price of rice, a rice yield index defined as the yield of rice relative to the average yield of corn, cassava and soybean, real gross revenues for rice, defined as the World price of rice times the rice yield index and the real capital cost per hectare for developing new irrigation systems. The variables which were assumed to influence the availability of publi resources and foreign exchange were the real gross nationa product and the real World price of oil. This latte variable was included because of its overwhelming influenc on government revenues and foreign exchange. Additiona variables tested in model specifications were: the import of rice and the imports of rice as a percentage of domesti production. These variables were included to see if th government goal of reduction in level and cost of import had a significant impact on investments. Specifications o the irrigation investment functions also required specification of the lag structure between the independen and dependent variables. Lags in the irrigation developmen process include lags between project appraisal and approval between approval and initiation of construction, and betwee initiation and completion. In Indonesia, which had substantial pipeline for irrigation projects, the lags have been compressed or lengthened substantially over time due to changes in government priorities or resources.[11]

Rosegrant (1990) developed an alternative method to the standard partial adjustment area response model which was the estimation of a system of share equations for area allocated to the main food crops. This approach represented the allocation of the finite land resource among a number of alternative crops as a process of allocation of shares of the land resources to the different crop activities, where by definition, the crop shares in total land area added to unity. Thus, the share of each crop in total area was estimated as a function of the net revenues for that crop and the net revenues for the other crops, the level of irrigation development (expressed as a share of total crop area), and the total crop area. With appropriate normalization of revenues and shares in the estimating equations, this approach had two main advantages to the partial adjustment area response functions. First, this systems approach to estimation of area response assured adding up of the shares to unity, so that changes in the

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[11]Rosegrant and E.Pasandaran, Irrigation investment in Indonesia :Trends and Determinants, Final Report, International Food Policy Research Institute, Washington, 1990.

allocation of total crop area across crops to changes in the independent variables were consistent. Second, the systems approach imposed homogeneity of degree zero in revenue, which again assured consistency in area to revenue.[12]

Ali (1990) developed a model to simultaneously estimate the price response assuming interdependence among crops. The model was applied to estimate own and cross price elasticities for five major crops in Pakistan, viz., wheat, cotton, rice, sugarcane and maize based on the production and expected wholesale price data for the period 1957-86. The study found little potential to enhance overall agricultural productivity by increasing the single crop price, since either the own price elasticities were low or, otherwise, the negative cross-price effects on the production of other crops were high. However, a ten per cent systematic improvements in terms of trade for agriculture would increase overall agricultural productivity by about six per cent in the long run.[13]

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[12] M.W.Rosegrant, Approches to Modelling the Impact of Irrigation Investment on Aggregate Production, Final Report, International Food Policy Research Institute, Washington, 1990.

[13] Mubarik Ali "The Price Response of Major Crops in Pakistan : An Application of Simultaneous Equation Model". **The Pakistan Development Review**, 29(2):305-325, 1990.

Rosegrant and Kasryno (1991) developed a standard model which characterised by formal theoretical derivations of the input use and output supply functions. There were three theoretical ways to derive the output supply, namely (a) The Nerlove's partial adjustment model by specifying area and yield functions (primal) (b) profit function (dual) approach and (c) quasi-fixed input model. The profit function would be preferred over Nerlove's model as the former would estimate the input use and output supply simultaneously. The Nerlovian approach worked well for area and poorly for yield. Moreover, expected profit would be the decision variable rather than the output in the area response model. They have suggested a valuable extension over these two traditional supply response models because these two models did not handle quasi-fixed inputs and changing technology. A simultaneous equation model was suggested to deal with quasi-fixed inputs, seasonaly fixed factors and a method to deal with changing technology. In this model, total irrigated area was taken as quasi-fixed input and area by crop as seasonaly fixed input. In this new methodology, quasi-fixed input, crop area and yield were determined simultaneously.[14]

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[14] M.W.Rosegrant and F.Kasryno, Food Crop Supply *Response in Indonesia - A System Approach, Final Report*, International Food Policy research Institute, Washington, 1991.

McGuirk and Mundlak (1991) has developed a theoretical framework for choice of techniques in production, based on the neoclassical investment theory. It permitted separate determination of optimal input and output combinations along a given production function (The Intratechnique effect). They determined optimal combination of techniques known as Intertechnique effect. Separate determination of these two effects was important for policy purposes, since their impact on production, income and other economic outcomes were likely to be different. In this approach, changes in optimal input and output combinations for each crop have been distinguished from the changes in the allocation of quasi-fixed input across crops. Further technology and levels of quasi-fixed inputs have been treated as endogenous variables. The frame work suggested by them provided a structure within which the dynamic effects of technology, prices and investments could be examined.[15]

Shanmugam (1992) fitted Cobb-Douglas type function and studied the area response of hybrid cotton seed crop using single equation regression model. The share of hybrid cotton seed crop to the gross area was influenced by

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[15] A.McGuirk and Y.Mundlak, Incentives and Constraints in the Transformation of Punjab Agriculture, Final Report, International Food Policy Research Institute, Washington, 1991.

irrigation intensity and farm income. As expected, irrigation was the important factor that influenced the farmers to adopt a new technology. The other important factor was the farm income denoting the investment capacity of the farmer which was needed for the hybrid seed production since it was a capital intensive enterprise. He applied the dummy variables to find out the shift in the supply curve due to scale effect. He concluded that the supply curve shifted upward in the large farms with a change in intercept with common slopes.[16]

Chen and Ito (1992) developed an econometric model needed to adequately investigate supply response each time if the provisions of government programmes were changed. It has been suggested that a methodology for combining time-series data from time periods governed by several combinations of farm commodity programmes have to be considered. The methodologies were first to develop econometric modelling techniques by incorporating a consistent framework of implicit revenue functions and a policy switching procedure for supply response analysis. Secondly they investigated producers' behaviour in response to changes in expected net operating returns for both programme participants and nonparticipants. The policy

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[16] T.R.Shanmugam, "The Use of Dummy Variable Approach in Testing Regressions", **Journal of Indian Society of Agricultural Statistics**, 54(1):37-45, 1992.

switching procedure consisted of two equations that estimated Operating Returns Over Variable Costs (OROVC) incorporating different programme provisions over time, then utilized operating returns over variable costs to estimate supply response relations. By using the switching procedure, acreage response equations over different farm programmes were combined in a system to account for changes in the model specifications under conditions of major policy shifts. The econometric methods developed here were applied to the U.S. rice sector to examine the sensitivity of the model to changing farm programmes for policy evaluation purposes between 1961 and 1988.[17]

Kumar and Mathur (1992) analysed the response of market supply to changes in price and non-price factors like irrigation, acreage and productivity and included these non price factors in the model as they were important for forecasting the supply of commodities and formulating agricultural price policy. In crops which were almost totally marketed, the elasticity of output and market supply could be regarded as approximately equal. But in crops such as rice, wheat and other food grains where a substantial

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17 D.T.Chen and S.Ito, "Modelling Supply Response with Implicit Revenue Function", **American Journal of Agricultural Economics**, 74(1):186-196, 1992.

part of production was retained by the farmers for home consumption, the responsiveness of the marketed supply would be measured separately as these might be different from the responsiveness of crop output supply. Previous studies did not take into account the factor prices and thus were of limited use for answering the policy questions related to factor and product price policy and investment decisions. Under the influence of input intensive technology, the factor prices were bound to affect the output response and marketed surplus. They provided a structure within which the dynamic effect of factor product prices and quasi-fixed variables on marketed surplus could easily be analysed to answer the policy questions on the required adjustments in rice price and irrigation investments necessary to compensate for cost push inflation in order to reach different consumption and welfare goals of the country.[18]

Rosegrant (1992) applied the choice of technique approach with extension of the investment component. This approach provided a rich theoretical frame work comprising three supply response models. The first supply response

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[18]P.Kumar and V.C.Mathur, Demand and Supply Analysis of Rice in India: Methodological Issues, paper presented at Planning Workshop on Projections and Policy Implications of Medium and Long Term Rice Supply and Demand, International Rice Research Institute, Los Banos, 1991.

model was the single period decision problem in which the farmer's short run problem would be to allocate variable factors of production and quasi-fixed factors among the techniques of production. The quasi-fixed inputs might include research and extension expenditure, level of effort, irrigation investment or irrigated area and other infrastructure investment. In the single period decision problem, allocation of variable and quasi-fixed inputs across the techniques was conditioned on the exogenous availability of the quasi-fixed inputs in that period. Extension of this model to allow endogenous determination of the quasi-fixed inputs was through the multi period decision making. This decision problem was the second model formulated as an intertemporal optimization problem or multi period decision problem in which the farmer would select the time path of inputs that maximised the expected present value of the multi period cash flow of farm. This frame work described the desired stock of quasi-fixed input as a function of specified state variables. The actual stock of quasi-fixed inputs did not adjust instantaneously to changes in the desired stock of quasi-fixed inputs. Instead the changes in the desired stock were transformed into actual stock using a flexible accelerator model. In this third model it could be assumed that the quasi-fixed input was adjusted towards its desired level by a constant proportion of the difference between the designed and actual stock of quasi-fixed input.[19]

Simatupang and Sudaryanto (1992) developed a prototype model for rice supply and demand for Indonesia. The demand functions were estimated for different classes and region. Supply for rice, maize, cassava, soybean, sugar and wheat were computed as a function of irrigation investment and commodity prices. The supply elasticities were assumed to change over time as per the change in the consumption expenditure. They have also studied the government pricing and investment policies on demand and supply of various crops by specifying the level of irrigation investment, price policies and input subsidies.[20]

In the present study, supply of canal, system tank, non-system tank, well inside and well outside command area are determined simultaneously. For each source, supply of major crops area will also be estimated simultaneously with the rest of the systems. The levels of sources and crops are

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[19] M.W.Rosegrant, Determinants of Government Investment: Irrigation in Indonesia, Final Report, International Food Policy Research Institute, Washington, 1992.

[20] Pantjar Simatupang and Tahlim Sudaryanto, A Prototype Model for Rice Supply and Demand Analysis and Projection in Indonesia, Proceedings of Planning Workshop on Projections and Policy Implications of Medium and Longterm Rice Supply and Demand, International Rice Research Institute, Los Banos, 1992.

determined by constraints, incentives, resources, environment and lagged endogenous variables. The methodology suggested by McGuirk and Mundlak has been modified and applied in the present study. Detailed analytical frame work has been developed and presented in Chapter III. Given the nature of Seemingly Unrelated Regression Estimate (SURE), these simultaneous equations are estimated using Zellner (1963) efficient method.[21]

Economic Efficiency

Measurement of economic efficiency includes technical efficiency and allocative efficiency. Technical efficiency refers to the proper choice of production function among all those actively in use by farms. Allocative efficiency refers to proper choice of input combinations. The core of economic theory is concerned with the allocative efficiency i.e., the marginal value products of some or all factors might be equal to their marginal factor costs. The other important aspect of economic decision making process is to produce the greatest possible output from a given set of inputs. It means that the technical decision is efficient.

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[21] A.Zellner, "Estimates for Seemingly Unrelated Regression Equations: Some Exact Finite Sample Results", **Journal of the American Statistical Association**, 58 (3): 977-992, 1963.

A probabilistic frontier function could be used to measure both allocative and technical efficiency.[22]

Aigner et al. (1977) applied the stochastic frontier production function in the analysis of aggregate data on the U.S. primary metals industry and U.S. agricultural data for 6 years. For these applications, the stochastic frontier was not significantly different from the average response function.[23] Similar results were obtained by Meensen and Van den Broeck (1977) in their analyses for ten French manufacturing industries.[24]

The application of the stochastic frontier model to farm-level agricultural data was presented by Battese and Corra (1977). Data from the 1973-74 Australian grazing industry survey were used to estimate deterministic Cobb-Douglas production frontiers for the three states included in the Pastoral Zone of Eastern Australia. The variance of the farm effects was found to be a highly significant

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[22] T.R.Shanmugam and K.Palanisami, "Measurement of Economic Efficiency-Frontier Function Approach",**Journal of Indian Society of Agricultural Statistics**,45(2):235-242, 1993.

[23] D.J. Aigner, C.A.K Lovell and P.Schmidt "Formulation and Estimation of Stochastic Frontier Production Function Models", **Journal of Econometrics**, 6(1):21-37, 1977.

[24] W.Meensen and J.Van den Broeck, "Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error", **International Economic Review**, 18(4): 435-444, 1977.

proportion of the total variability of the logarithm of the value of sheep production in all states. The r - parameter estimates exceeded 0.95 in all cases. Hence the stochastic frontier production functions were significantly different from their corresponding deterministic frontiers. Technical efficiency of farms in the regions was not addressed by Battese and Corra.[25]

Kalirajan (1981) estimated a stochastic frontier Cobb-Douglas production function using data from 70 rice farmers for the rabi season in a district in India. The variance of farm effects was found to be a highly significant component in describing the variability of rice yields (the estimate for the r -parameter was 0.81). Kalirajan proceeded to investigate the relationship between the difference between the estimated 'maximum yield function' and the observed rice yields and such variables as farmer's experience, educational level, number of visits by extension workers, etc. In this second stage analysis, Kalirajan noted the policy implications of these findings for improving crop yields of farmers.[26]

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[25] G.E.Battese and G.S.Corra, "Estimation of a Production Frontier Model with Application to the Pastoral Zone of Eastern Australia", **Australian Journal of Agricultural Economics**, 21(2): 169-179, 1977.

[26] K.P.Kalirajan, "An Econometric Analysis of Yield Variability in Paddy Production", **Canadian Journal of Agricultural Economics**, 29(2): 283-294, 1981.

Bagi (1982) used the stochastic frontier Cobb-Douglas production function model to determine whether there were any significant differences in the technical efficiencies of small and large crop and mixed-enterprise farms in West Tennessee. The variability of farm effects were found to be highly significant and the mean technical efficiency of mixed enterprise farms was smaller than that for crop farms (about 0.76 versus 0.85, respectively). However, there did not appear to be significant differences in mean technical efficiency for small and large farms, irrespective of whether the farms were classified based on acreage or value of farm sales.[27] Bagi (1984)considered the same farms as in Bagi (1982) to investigate whether there were any significant differences in the mean technical efficiencies of part-time and full-time farmers. No significant differences were apparent, irrespective of whether the part-time and full-time farmers were engaged in mixed farming or crop-only farms.[28]

Bagi (1982) included empirical results on the estimation of a translog stochastic frontier production

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[27]F.S.Bagi, "Relationship between Farm Size and Technical Efficiency in West Tennesse Agriculture", **Southern Journal of Agricultural Economics**, 14(1):139-144, 1982.

[28]F.S.Bagi, "Stochastic Frontier Production Function and Farm Level Technical Efficiency of Full Time and Part Time Farms in West Tennessee", **North Central Journal of Agricultural Economics**, 6(1): 48-55, 1984.

function using data from 34 share cropping farms in India. The parameters of the model were estimated using corrected ordinary least squares regression. The Cobb-Douglas functional form was judged not to be an adequate representation of the data given the assumptions of the translog model. For these Indian farm data, the variance of the non-negative farm effects was only a small proportion of the total variance of farm outputs ($r = 0.15$). The individual farm technical efficiencies were predicted to be between 0.92 and 0.95. These high technical efficiencies are consistent with the relatively low variance of farm effects which implies that the stochastic frontier and the average production function are expected to be quite similar.[29]

Bagi and Huang (1983) estimated a translogarithmic stochastic frontier production function using the data on the Tennessee farms. The Cobb-Douglas stochastic frontier model was found not to be an adequate representation of the data, given the specifications of the translog model for both crop and mixed farms. The parameters of the model were estimated by corrected ordinary least squares regression.

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[29] F.S.Bagi, "Economic Efficiency of Share Cropping: Reply and Some Further Results", **Malaysian Economic Review**, 27(1): 86-95, 1982.

The mean technical efficiencies of crop and mixed farms were estimated to be 0.73 and 0.67, respectively. Individual technical efficiencies of the farms were predicted using the predictor exp.$(-U_i)$ where U_i is the estimated conditional mean of the ith farm effect (suggested by Jondrow, Lovell, Materov and Schmidt,1982).[30] These technical efficiences varied from 0.35 to 0.92 for mixed farms and 0.52 to 0.91 for crop farms.[31]

Kalirajan and Flinn (1983) outlined the methodology by which the individual firm effects can be predicted and applied the approach in their analysis of data on 79 rice farmers in the Philippines. A translog stochastic frontier production function was assumed to explain the variation in rice output in trans terms of several input variables. The parameters of the model were estimated by the method of maximum likelihood. The Cobb-Douglas model was found to be an inadequate representation for the farm-level data. The individual technical efficiencies ranged from 0.38 to 0.91. The predicted technical efficiencies were regressed on

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[30] J.Jondrow, C.A.K.Lovell, I.S.Materov and P.Schmidt "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model", **Journal of Econometrics**, 19(2): 233-238, 1982.

[31] F.S.Bagi and C.J.Haung, "Estimating Production Technical Efficiency for Individual Farms in Tennessee", **Canadian Journal of Agricultural Economics**, 31(2):249-256, 1983.

several farm-level variables and farmer-specific characteristics. It was concluded that the practice of transplanting rice seedlings, incidence of fertilization, years of farming and number of extension contacts had significant influence on the variation of the estimated farm technical efficiencies.[32]

Russell and Young (1983) estimated a deterministic Cobb-Douglas frontier using corrected ordinary least-squares regression with a cross-section of 56 farms in the North-West region of England during 1977-78. The dependent variable was total revenue obtained from the crop, livestock and miscellaneous activities of the farms involved. Technical efficiencies for the individual farms were obtained using both the Timmer and Kopp measures. These two measures of technical efficiency gave approximately the same values and the same rankings for the 56 farms involved. The Timmer technical efficiencies ranged from 0.42 to 1.00, with an average of 0.73 and sample standard deviation 0.11. Russell and Young did not make any strong conclusions as to the policy implication of these results.[33]

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[32] K.P.Kalirajan and J.C.Flinn, "The Measurement of Farm-specific Technical Efficiency", **Pakistan Journal of Applied Economics**, 2(1): 167-180, 1983.

[33] N.P.Rusell and T.Young, "Frontier Production Functions and the Measurement of Technical Efficiency", **Journal of Agricultural Economics**, 34(1):139-150, 1983.

Knotos and Young (1983) conducted similar frontier analyses to those of Russell and Young (1983) for a data set for 83 Greek farms for the 1980-81 harvest year. Knotos and Young applied a Box-Cox transformation to the variables of the model and obtained similar elasticities to those obtained by estimating the Cobb-Douglas production function by ordinary least squares regression. Since the likelihood ratio test indicated that the Box-Cox model was not significantly different from the traditional Cobb-Douglas model, the deterministic frontier model was estimated by corrected ordinary least squares regression. The estimated frontier model was used to obtain the values of the Kopp measure of technical efficiency for the individual farms involved. These technical efficiencies ranged from 0.30 to 1.00, with an average of 0.57, indicating that considerable technical inefficiencies existed in the Greek farms surveyed.[34]

Huang and Bagi (1984) assumed a modified translogarithmic stochastic frontier production function to estimate the technical efficiencies of individual farms in India. It was found that the Cobb-Douglas stochastic frontier was not an adequate representation for describing

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[34]A. Knotos and T. Young, "An Analysis of Technical Efficiency on a Sample of Greek Farms", **European Review of Agricultural Economics**, 10(2): 271-280, 1983.

the value of farm products, given the specifications of the translog model. The variance of the random effects was a significant component of the variability of value of farm outputs. Individual technical efficiencies ranged from about 0.75 to 0.95, but there appeared to be no significant differences in the technical efficiencies of small and large farms.[35]

Dawson (1985) analysed 4 years of data for the 56 farms. Three estimators for the technical efficiency of the individual farms were presented which involved a two step, ordinary least squares procedure, an analysis of covariance method and the linear programming procedure suggested by Aigner and Chu (1968).[36] The technical efficiency measures obtained by the three methods exhibited wide variations and the estimated correlation coefficients were quite small. Dawson claimed that there was indication that the technical efficiencies were directly related to the size of the farm operation.[37]

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[35] C.J.Haung and F.S.Bagi, "Technical Efficiency on Individual Farms in North West India", **Southern Economic Journal**, 51(1): 108-115, 1984.

[36] D.J.Aigner and S.F.Chu, "On Estimating the Industry Production Function",**American Economic Review**, 58(5):826-839, 1968.

[37] P.J.Dawson, "Measuring Technical Efficiency from Production Functions: Some Further Estimates",**Journal of Agricultural Economics**, 36(1): 31-40, 1985.

Taylor _et al_. (1986) considered a deterministic Cobb-Douglas frontier production function for Brazilian farmers to investigate the effectiveness of a World Bank sponsored agricultural credit programme in the State of Minas Gerais. The parameters of the frontier model were estimated by corrected ordinary least-squares regression and the maximum-likelihood method under the assumption that the non-negative farm effects had gamma distribution. The authors did not report estimates for different frontier functions for participant and non-participant farmers in the agricultural credit programme and test if the frontiers were homogeneous. It appears that the technical efficiencies of participant and non-participant farmers were estimated from the common production frontier reported in the paper. The average technical efficiencies for participant and non-participant farmers were reported to be 0.18 and 0.17, respectively. The authors concluded that these values were not significantly different and that the agricultural credit programme did not appear to have any significant effect on the technical efficiencies of participant farmers.[38]

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[38] T.G.Taylor, H.E.Drummond and A.T.Gomes, "Agricultural Credit Programs and Production Efficiency: An Analysis of Traditional Farming in South Eastern Minas Gerais, Brazil", **Journal of Agricultural Economics**, 68(1): 110-119, 1986.

Bravo-Ureta (1986) estimated the technical efficiencies of dairy farms in the New England region of the United States using a deterministic Cobb-Douglas frontier production function. The parameters of the production frontier were estimated by linear programming methods involving the probabilistic frontier approach. Using the 96 per cent probabilistic frontier estimates, Bravo-Ureta obtained technical efficiencies which ranged from 0.58 to 1.00, with an average of 0.82. He concluded that technical efficiency of individual farms was statistically independent of size of the dairy farm operation, as measured by the number of cows.[39]

Taylor and Shonkwiler (1986) estimated both deterministic and stochastic production frontiers of Cobb-Douglas type for participants and non-participants of the World Bank sponsored credit programme for farmers in Brazil. The parameters of the frontiers involved were estimated by maximum likelihood methods, given the assumptions that the farm effects had gamma distribution in the deterministic frontier and half normal for the stochastic frontier. The authors did not report that statistical tests had been conducted on the homogeneity of the frontiers for

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[39] B.E.Bravo-Ureta, "Technical Efficiency Measures for Dairy Farms Based on a Probabilistic Frontier Function Model", **Canadian Journal of Agricultural Economics**, 34(3): 399-415, 1986.

participants and non-participant farmers. Farm-level technical efficiencies were estimated for all the frontiers. Given the stochastic frontiers, the average technical efficiencies for participants and non-participants were 0.714 and 0.704, respectively, and were not significantly different. However, given the assumptions of the deterministic frontiers, the average technical efficiencies were 0.185 and 0.059, respectively, and were significantly different.[40]

Huang et al. (1986) adopted a stochastic profit function approach to investigate the economic efficiency of small and large farms in two states in India. The variability of farm effects was highly significant and individual farm economic efficiencies tended to be greater for large farms than small farms (the average economic efficiencies being 0.84 and 0.80 for large and small farms, respectively). The authors also considered the determination of optimal demand for hired labour under conditions of uncertainty.[41]

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[40] T.G.Taylor and J.S.Shonkwiler, "Alternative Stochastic Specifications of the Frontier Production Function in the Analys's of Agricultural Credit Programs and Technical Efficiency", Journal of Development Economics, 21(1): 149-160, 1986.

[41] C.J.Haung, A.M.Tang and F.S.Bagi, "Two Views of Efficiency in Indian Agriculture", Canadian Journal of Agricultural Economics, 34(2): 209-226, 1986.

Kalirajan and Shand (1986) investigated the technical efficiency of rice farmers within and without the Kembu Irrigation Project in Malaysia during 1980. Given the specifications of a translog stochastic frontier production function for the output of the rice farmers, the Cobb-Douglas model was not an adequate representation of the data. Maximum likelihood methods were used for estimation of the parameters of the models and the frontiers for the two groups of farmers were significantly different. Kalirajan and Shand reported that the individual technical efficiencies ranged from about 0.40 to 0.90, such that the efficiencies for those outside the Kembu Irrigation Project were slightly narrower. They concluded that their results indicated that the introduction of new technology for farmers does not necessarily result in significantly increased technical efficiencies over those traditional farmers.[42]

Ekanayake and Jayasuriya (1987) estimated both deterministic and stochastic frontier production function of Cobb-Douglas type for two groups of rice farmers in an irrigated area in Sri Lanka. The parameters of the two

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[42] K.P.Kalirajan and R.T.Shand, "Estimating Location - Specific and Firm Specific Technical Efficiency:An Analysis of Malaysian Agriculture", Journal of Economic Development, 11(1): 147-160, 1986.

frontiers were estimated by maximum likelihood and corrected ordinary least squares methods. In only the 'tail reach' irrigated area, the stochastic frontier appeared to be significantly different from the deterministic model. Individual farm technical efficiencies were estimated for both regions. The estimates obtained for the farms in the 'head reach'area (for which the stochastic frontier appeared not to be significantly different from the deterministic frontier) were vastly different for the two different stochastic frontiers.[43]

Ekayanake (1987) further discussed the data considered by Ekanayake and Jayasuriya (1987)[44] and used regression analysis to determine the farmer specific variables which had significant effects in describing the variability in the individual farm technical efficiencies in the 'tail reach' of the irrigation area involved. Allocative efficiency was also considered in the empirical analysis.[45]

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[43] S.A.B.Ekanayake and S.K.Jayasuriya "Measurement of Farm-specific Technical Efficiency: A Comparison of Methods", **Journal of Agricultural Economics**, 38(1): 115-122, 1987.

[44] S.A.B.Ekanayake and S.K.Jayasuriya, **Op.cit**, pp.115-122.

[45] S.A.B.Ekanayake, "Location Specificity, Settler Type and Productive Efficiency:A Study of the Mahaweli Project in Sri Lanka", **Journal of Development Studies**, 29(3): 509-521, 1987.

Aly *et al*. (1987) investigated the technical efficiency of a sample of Illinois grain farms by using a deterministic frontier production function of ray-homothetic type. The authors presented a concise summary of the different approaches to frontier production functions, including stochastic frontiers. The deterministic ray-homothetic frontier, which was estimated by Corrected Ordinary Least Square regression (COLS), had the output and input variables expressed in revenue terms rather than in physical units. Hence the technical efficiencies also reflected allocative efficiencies. The mean technical efficiency for the 88 grain farms involved was 0.58 which indicated that considerable inefficiency existed in Illinois grain farms. The authors found that larger farms tended to be more technically efficient than smaller ones, irrespective of whether acreage cultivated or gross revenue was used to classify the farms by size of operation.[46]

Battese and Coelli (1988) applied their panel-data model in the analysis of data for dairy farms in New South Wales and Victoria for the three years - 1978-79, 1979-80 and 1980-81. Given the specifications of the stochastic

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[46] H.Y.Aly, K.Belbase, R.Grabowski and S.Kraft, "The Technical Efficiency of Illinois Grain Farms : An Application of a Ray - Homothetic Production Function", **Southern Journal of Agricultural Economics**, 19(1): 69-78, 1987.

frontier Cobb-Douglas production function involved, the hypothesis that the non-negative farm effects had half normal distribution was rejected for both states. Individual farm technical efficiencies ranged from 0.55 to 0.93 for New South Wales farms, whereas the range was 0.30 to 0.93 for Victorian farms.[47]

Battese et al. (1989) estimated a stochastic frontier production function for farms in an Indian village for which data were available for upto ten years. Although the stochastic frontier was significantly different from the corresponding deterministic frontier, the hypothesis that the non-negative farm effects had half normal distribution was not rejected. Technical efficiencies ranged from 0.66 to 0.91, with the mean efficiency estimated by 0.84.[48]

Kalirajan and Shand (1989) estimated the time-invariant panel data model using data for Indian rice farmers over five consecutive harvest periods. The farm

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[47] G.E.Battese and T.J.Coelli, "Prediction of Firm - Level Technical Efficiencies with a Generalized Frontier Production Function and Panel Data", **Journal of Econometrics**, 38(3): 387-399, 1988.

[48] G.E.Battese, T.G.Coelli and T.C.Colby, "Estimation of Frontier Production Functions and the Efficiencies of Indian Farms using Panel Data from ICRISAT's Village Level Studies", **Journal of Quantitative Economics**, 5(2): 327-348, 1989.

effects were found to be a highly significant component of the variability of rice output, given the specifications of a translog stochastic frontier production function. Individual technical efficiencies were estimated and ranged from 0.64 to 0.91, with average 0.70. A regression of the estimated technical efficiencies on farm specific variables indicated that farming experience, level of education, access to credit and extension contacts had significant influences on the variation of the farm efficiencies.[49]

Kalirajan (1989) predicted technical efficiencies of individual farmers (which he called human capital) involved in rice production in two regions in the Philippines in 1984-85. A Cobb-Douglas stochastic frontier model was assumed to be appropriate in the empirical analysis. The predicted technical efficiencies were regressed on several farm and farmer specific socio - economic variables to discover the significant effects on the variation in the technical efficiencies.[50]

Ali and Flinn (1989) estimated a stochastic profit frontier of modified translog type for Basmati rice farmers

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[49] K.P.Kalirajan and R.T.Shand, "A Generalized Measure of Technical Effic.ency", **Applied Economics**, 21(1): 25-34, 1989.

[50] K.P.Kalirajan, "On Measuring the Contribution of Human Capital to Agricultural Production", **Indian Economic Review**, 24(2): 247-261, 1989.

in Pakistan's Punjab. After estimating the technical efficiency of individual farmers, the losses in profit due to technical inefficiency were obtained and regressed on various farmers and farm specific variables. Factors which were significant in describing the variability in profit/losses were level of education, off-farm employment, unavailability of credit and various constraints associated with irrigation and fertilizer application.[51]

Dawson and Lingard (1989) used a Cobb-Douglas stochastic frontier production function to estimate technical efficiencies of Philippine rice farmers using four years of data. The four stochastic frontiers estimated were significantly different from the corresponding deterministic frontiers, but the authors did not adopt any panel data approach or test if the frontiers had homogeneous elasticities. The individual technical efficiencies ranged between 0.10 and 0.99. With the means between 0.60 and 0.70 for the 4 years involved.[52]

Bailey et al. (1989) estimated a stochastic model involving technical, allocative and scale inefficiencies for

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[51] M.Ali and J.C.Flinn, "Profit Efficiency Among Basmati Rice Producers in Pakistan's Punjab", **American Journal of Agricultural Economics**, 71(2): 303-310, 1989.

[52] P.J.Dawson and J.Lingard, "Measuring Farm Efficiency Overtime on Philippine Rice Farms", Journal **of Agricultural Economics**, 40(2): 168-177, 1989.

cross sectional data on 68 Ecuadorian dairy farms. The technical inefficiencies of individual farms were about 12 per cent with little variation being displayed by individual farms. However, the authors found that the losses due to technical inefficiencies ranged from 20 to 25 per cent.[53]

Kumbhakar et al. (1989) used a system approach to estimate technical, allocative and scale inefficiencies for Utah dairy farmers. The stochastic frontier production function which was specified included both endogenous and exogenous variables. The endogenous variables included were labour (including family and hired labour) and capital (the opportunity cost of capital expenses on the farm), whereas the exogenous variables included level of formal education, off-farm income and measures of farm size for the farmers involved. Both types of explanatory variables were found to have significant effects on the variation of farm production. Technical efficiency of farms was found to be positively related to farm size.[54]

Bravo-Ureta and Rieger (1990) estimated both deterministic and stochastic frontier production functions

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[53] D.V.Bailey, B.Biswas, S.C.Kumbhakar and B.K.Schulthies, "An Analysis of Technical, Allocative and Scale Inefficiency:the Case of Ecaudorian Dairy Farms", **Western Journal o. Agricultural Economics**, 14(1): 30-37, 1989.

[54] S.C.Kumbhakar, B.Biswas and D.V.Bailey, "A Study of Economic Efficiency of Utah Dairy Farmers : A System Approach", **Review of Economics and Statistics**, 71(4): 595-604, 1989.

for a large sample of dairy farms in the northeastern states of the U.S.A. for the years 1982 and 1983. The Cobb-Douglas functional form was assumed to be appropriate. The parameters of the deterministic frontiers were estimated by linear programming, corrected ordinary least squares regression and maximum likelihood methods (assuming that the non-negative farm effects had gamma distribution). The stochastic frontier model was estimated by maximum likelihood techniques (given that the farm effects had half normal distribution). The stochastic frontier model had significant farm effects for 1982 but it was apparently not significantly different from the deterministic frontier in 1983. The estimated technical efficiencies of farms obtained from the three different methods used for the deterministic model showed considerable variability but were generally less than those obtained by use of the stochastic frontier model. However, Bravo-Ureta and Rieger found that the technical efficiencies obtained by the different methods were highly correlated and gave similar ordinal rankings of the farms.[55]

Ali and Chaudhry (1990) estimated deterministic frontier production functions in their analyses of a cross-section of farms in four regions of Pakistan's Punjab. The

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[55] B.E.Bravo-Ureta and L.Rieger, "Alternative Production Frontier Methodologies and Dairy Farm Efficiencies", ***Journal of Agricultural Economics***, *41(2)*: 216-226 1990.

parameters of the Cobb-Douglas frontier functions for the four regions were estimated by linear programming methods. Although the frontier functions were not homogeneous among the different regions, the technical efficiencies in the four regions ranged from 0.80 to 0.87 but did not appear to be significantly different.[56]

For the present study, the production function has been defined as the relationship that describes the maximum possible aggregate crop output for the given combination of crop area in different irrigation sources. A production function estimated by Ordinary Least Square method (OLS) shows an average response and does not represent the frontier. This average function fails to measure economic efficiency. Timmer suggested linear programming approach to convert average production function into a probabilistic production function for U.S.agriculture time series data from 1960 to 1967.[57] Timmer's probabilistic approach is applied in the present study to measure both technical and allocative efficiency of major crops under different irrigation sources.

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[56] M.Ali and M.A.Chaudhry, "Inter-Regional Farm Efficiency in Pakistan's Punjab: A Frontier Production Function Study", **Journal of Agricultural Economics**, 41: 62-74, 1990.

[57] C.P.Timmer, "Using a Probabilistic Frontier Function to measure Technical Efficiency", **Journal of Political Economy**, 79: 776-794, 1971.

DESIGN OF THE STUDY

CHAPTER III

DESIGN OF THE STUDY

Research design is a series of guide-posts to keep the researcher in the right direction. For successful conduct of research study and drawing meaningful inference, an appropriate methodology is indispensable. The choice of study area, method of data collection, sources and nature of data, analytical framework and tools of analysis used in this study are discussed in this chapter.

The Choice of Study Area

The present study was undertaken in Tamil Nadu covering all sources of irrigation in the state. Thus Tamil Nadu State covering all agro climatic zones forms the universe of the study.

Sources and Nature of Data

The study was primarily based on secondary data published in official documents of Agriculture and Irrigation Departments. The nature of information covered were sourcewise irrigated area, cropwise irrigated area in each source, production of crops, production index, land use pattern, fertilizer and pesticide availability, rainfall, population, infrastructures, agricultural gross domestic product, prices, revenues of various crops grown, and gross irrigated area of all sources from 1960-61 to 1989-90. Time series data on all the above mentioned items were collected district-wise for the period 1960-61 to 1989-90 and added across the districts to arrive at the state level data. It has been cross checked with the available figures for the state as a whole. Wherever time series information were not available, Cost of Cultivation of Principal Crops (CCPC) data and National Sample Survey (NSS) data were collected and included for the analysis.

Analytical Frame Work

The main focus in Tamil Nadu during the period under consideration is the development of water resources. An analysis of this period must explicitly take into account the effect of the change in water resources on product supply, yield and input demand. Output is determined by water resources, other inputs and technology. Given the available technology, the selected level of inputs depends on product prices, factor prices, environment and constraints. Included among the economic variables in the present study are water sources as quasi fixed inputs (inputs that cannot vary immediately regardless of reason in response to price variations), seasonally fixed inputs (crops area in different water sources), resources, constraints, environment and infrastructure. The available technology set contains all crops that potentially can be cultivated, whereas the implemented technology set contains those crops that actually are implemented. Thus the distinction between available and implemented technology has important implications for empirical analyses. It is important to identify the underlying technology, incentives, resources, environment and constraints in order to obtain a useful empirical description of the production process. Data on inputs, constraints, incentives, resources, environmental variables and output in the present study describe only the implemented technology in different production environments commanded by different water sources.

The Optimization Frame Work

Given the discussion above, the following optimisation problem is developed by choosing inputs V_j, b_j that maximise the lagrangian function L[1].

$$L = \Sigma_j p_j F_j(v_j b_j E) - \Sigma_j w v_j + \lambda(b - \Sigma_j b_j), \qquad (1)$$

so that $F_j(.) \varepsilon T$,

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[1]A.Mc Guirk and Y. Mundlak, Incentives and Constraints in the Transformation of Punjab Agriculture, Final Report, International Food Policy Research Institute, Washington, D.C., 1991.

Where

T = the set of all available techniques, or simply, available technology in different water sources.

p_j = the price of the product of crop j ;

v_j = the variable factors ;

w = the vector of prices of the variable factors (v_j) ;

b = the value of the constraint for the fixed factors of production that are allocated to the various crops (b_j) ;

E = the relevant characteristics of the environment in which crop j is implemented ; and

λ = a vector of shadow prices for the constraints.

The Kuhn-Tucker necessary conditions for a solution are

$$L_{v_j} = p_j F_{v_j} - w \leq 0, \tag{2}$$

$$L_{b_j} = p_j F_{b_j} - \lambda \leq 0, \tag{3}$$

$$\Sigma(L_{v_j} v_j + L_{b_j} b_j) = 0, \tag{4}$$

$$v_j \geq 0, \; b_j \geq 0, \tag{5}$$

$$L_{\lambda} = \sum b_j - b \leq 0, \tag{6}$$

$$\lambda L_{\lambda} = 0, \tag{7}$$

Where L_{v_j}, F_{v_j}, F_{b_j}, L_{b_j} and L_λ are vectors of the first partial derivatives. The solution can be described as

$$v_j^*(S),\ b_j^*(S),\quad \lambda_j^*(s),$$

Where s represents the exogenous variables of this problem which will be referred to as the state variables (s) ;

$$s \quad = \quad (b,\ p,\ w,\ E,\ T) \tag{8}$$

The solution to the maximization problem thus depends on the available technology (T), the environment (E), the constraints (b), and the product (p) and variable input prices (w). It is important to note that the solution determines both the crops used and the level of their use, as determined by the optimal allocation of fixed inputs (b_j^*) and variable inputs (v_j^*). This can be seen by rearranging equations (2), (3) and (4).

$$\Sigma_j(p_jF_{v_j} - w_j)v_j + \Sigma_j(p_jF_{b_j} - \lambda)\ b_j \quad = \quad 0 \tag{9}$$

If equation (2) or equation (3) is negative, then v_j^* = 0 or b_j^* = 0, respectively.

The optimal output of crop j is $y_j^* = F_j(v_j^*, b_j^*, E)$. The implemented technology (IT), the collection of all implemented crops, is a subset of T. As such, the envelope of IT is in general not the same as the envelope of T. The difference, of course, is due to the constraints encountered by the decision maker.

The implemented technology, IT, can be described formally by

$$IT(b, p, w, E, T) = \{ F_j (v_j, b_j, E) / [F_j(v_j^*, b_j^*, E) > 0], F_j \in T \} \quad (10)$$

The number of implemented crops depends on the number of constraints or the dimentionality of b. In this general formulation, no limit is set on the number of state variables except that it is finite. Thus it is possible to apply the formulation to a variety of applications.

Given the usual regularity conditions for F_j and given a particular set of state variables, equation (9) describes a well-behaved technology. Consequently, a profit function can be derived:

$$\pi(s) = \Sigma P_j F_j(v_j^*(s), b_j^*(s), E) - \Sigma w_j v_j^*(s) \quad (11)$$

The various theorems dealing with the duality between the profit function and the production function hold true conditional on s. Specifically, the frontier of IT(S) is dual to $\pi(s)$ and vice versa. Using Hotelling's lemma, the factor demand is

$$-\frac{\partial \pi(s)}{\partial w} = v^*(s) \qquad (12)$$

Equation (12) expresses the input demand aggregated over crops. Similarly, the supply of output of crop j is given by

$$y_j^*(s) = \frac{\partial \pi(s)}{\partial p_j} \qquad (13)$$

If there is more than one source producing a given crop, then

$$\frac{\partial \pi(s)}{\partial p_i} = \Sigma_j y^*_{ji} = y_i^* \qquad (14)$$

Where y^*_{ji} is the j^{th} source used to produce the i^{th} crop and y_i^* is the total output of crop i. Finally, the aggregate value of supply is given by

$$y^*(s) = \Sigma\, p_j y_j^*(s) \qquad (15)$$

It is important to note that, within this framework, a change in a state variable generates two effects on the optimal variable inputs and outputs. First, a change in a state variable may lead to variations in the optimal combinations of inputs and outputs along a given production function. This intratechnique effect is the effect usually considered in supply analyses. The second effect due to a change in a state variable describes the shift in the production function illustrating the change in the optimal composition of outputs or crops. It is referred to here as the intertechnique effect. The impact of these two effects on the relationship between changes in state variables and output by crop may be very different. Thus, a distinction between these two effects and an understanding of the relative importance of these effects is necessary to fully understand growth in output for crops that can be produced by more than one source.

Optimization by Stages

In general, production is not instantaneous, so input usage decisions can be revised as the information set changes. In terms of crop production, farmers decide how to allocate their area among the different crops and techniques given their information set at the time of planting.[2] Once the crop has been planted

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[2]J.M. Antle, "Sequential Decision Making in Production Models", **American Journal of Agricultural Economics,** 65(2) : 282-290, 1983.

farmers can change output only by influencing yield. The extent to which yield, and thus output, can be altered later in the production process can be only be determined empirically.

In terms of the crop production decisions, it is assumed that at stage 1, the optimization described by equation (1) is used to determine the initial allocations of land and other fixed inputs to the various sources. Stage 2 of the decision problem can be formulated similarly except that this decision is made conditional on the optimal area allocations chosen in Stage 1. That is, the optimal area allocations are included among the relevant state variables in the stage 2 decisions. To be more explicit, the vector of the state variables for stage 1 of the optimization problem is

$$s^1 = (b^1, p^1, w^1, E, T) \tag{16}$$

where b^1, p^1, w^1 represent the constraints and the expected product and input prices at planting time, respectively. The state variables for the stage 2 optimization problem are

$$s^2 = (b^2, p^2, w^2, E, T) \tag{17}$$

where b^2 differs from b^1 in that it contains, among the other constraints, the area allocated to each crop or product in stage 1 rather than the total area available, that is, b^2 contains $A_j = A_j(s^1)$. Further, p^2 and w^2 are producers' updated expected product and input prices. Consequently, the optimal inputs of stage 2 are functions of s^2 and s^1, and the optimal output can be written as

$$Q_1^* = F_j(A_j(s^1), v_j(s^1, s^2), b_j(s^1, s^2)) \qquad (18)$$

within this framework, area is introduced explicitly as an input into the production function. Further, the other inputs are taken as the sum of their usage in the two stages, as input data are not detailed by stages.

Assuming that the production function is constant returns to scale in the inputs, equation (18) can be rewritten as a product of area and yield :

$$Q_j = A_j(s^1), Y_j(s^1, s^2) \qquad (19)$$

The two components of equation (19), yield and area, can be multiplied to arrive total output. If there is more than one source to produce a given crop, the total output can also be decomposed into source-wise.

Quasi-Fixed Inputs

In the present study, water sources are taken as quasi fixed inputs as they cannot vary immediately. The decisions by producers to alter the availability of quasi-fixed inputs viz., tanks, wells and canal sources take into account the anticipated effect of changes in these inputs on costs and revenues over the lifetime of the investment. The effect of these decisions on future streams of income distinguishes these long-run decisions from the short-run decisions previously analyzed. It is this difference that allows the formulation of the decision process problem that can be estimated in stages. Such formulations of the investment decision are now common in the estimation of dynamic factor demand equations.[3]

To illustrate the recursive approach, consider a simple inter-temporal optimization problem. Suppose there is only one output production function, Q = F(v, K, T), where v is the variable input, K is capital or the quasi-fixed input, and T is technology. The supply price of K is q and it is assumed to be a function of the rate of investment and time, q(I, t). All

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[3]Y.Mundlak, "Long run Coefficients and Distributed Lag Analysis : A Reformulation", **Economica**, 35 (April) : 278-293, 1967.

other variables (Q, K and v) are functions of time. The net cash flow (R) of a competitive firm is

$$R(t) = p(t)\ F(K(t),\ v(t),\ T) - w(t) \cdot v(t) - q(t)\ [\dot{K}(t) + \delta K(t) + c(\dot{K})] \qquad (20)$$

where q(t) c(K) represents as internal cost of adjusting capital, p(t) and w(t) are the product and input prices, respectively, and δ is the rate of depreciation of K(t). The nonstochastic formulation of the problem calls for selecting a time path of inputs that maximize the present value of the stream of R(t) :

$$\text{Maximize} \quad \int_0^{\infty} e^{-rt}\ R(t)\ dt, \qquad (21)$$

subject to

$$K(0) = K_0, \text{ where } K_0 \text{ is given,}$$

$$I(t) = \dot{K}(t) + \delta K(t), \text{ and}$$

$$\lim_{t \to \infty} (e^{-rt}\ R(t)) = 0$$

Given an interior solution, the first-order condition for the vector of variable inputs requires

$$\frac{\partial R(t)}{\partial v(t)} = 0, \quad \frac{\partial F(.)}{\partial v(t)} = \frac{w(t)}{p(t)} \qquad (22)$$

and the Euler equation is

$$\frac{\partial R(t)}{\partial K(t)} - \frac{d}{dt}\left(\frac{\partial R(t)}{\partial K(t)}\right) = 0 \qquad (23)$$

Equation (22) implies that, along the optimal path, the quantity of input employed at a time t has no effect on revenues in subsequent periods and that the optimal levels of this input are determined by equating the input's marginal product to its real price in each period. Consequently, the optimization can be solved in steps. The first step is to determine the optimal level of v(t), as a function of both prices and K(t), for each period. The solution from this optimization problem is substituted into equation (2) to obtain a restricted profit function :

$$\pi(K(t),\ v^*(t),\ s(t),\ T)$$

where s is a vector of state variables that, in this case, contains only w and p. Although it is not explicitly indicated here, v^* is also a function of K(T), T and s(t).

Given this restricted profit function, the second stage in the optimization problem is to maximize

$$\int_0^\infty e^{-rt}\left\{\pi\ K(t),\ v^*(t),\ s(t),\ T) - q(t)\ [\dot{K}(t) + \delta K(t) + c(\dot{K})]\right\}\ dt, \qquad (24)$$

subject to the constraints of equation (21). Suppressing the dependence of the relevant functions on s and the time index, the Euler equation for this problem is

$$\frac{\partial \pi}{\partial K} - q(\delta + r - \hat{q}) - q(\hat{q} - r)\ c'(\dot{K}) + qc''(\dot{K})\ddot{K} = 0 \qquad (25)$$

where $\hat{q} = \dot{q}/q$, $\ddot{K}$ is the first derivative of $\dot{K}$ with respect to time, and c' is the first derivative of c. In the absence of internal costs of adjustment, that is, $c(\dot{k}) = 0$, the optimal time path of K(t), say $K^*(t)$, is obtained by solving

$$\frac{\partial \pi}{\partial K} - q(\delta + r - \hat{q}) = 0, \qquad (26)$$

which states that, at its optimal level, the value marginal productivity of capital is equal to the user cost, allowing for price appreciation. Since K^* is a function of the prices that enter the restricted profit function, a change in prices requires an adjustment in $K^*(t)$. This formulation assumes that the adjustment in capital can be performed in one step. As it is believed that firms do not adjust their capital stock instantaneously, the concept of cost of adjustment is introduced to account for the gradual adjustment from an arbitrary K(t) to the optimal level $K^*(t)$.[4]

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[4]R.E.Lucas, "Adjustment Costs and Theory of Supply", **Journal of Political Economy**, 75(4) : 321 - 334, 1967.

The present analysis can be extended to accommodate the choice-of-technique framework by simply using equation (11) as the expression for π in equation (24). In terms of the current problem, however, the first stage in the decision process, which is conditional on a given time path for the quasi-fixed inputs, for example, K(t), is decomposed into two separate components - the area allocation decision and the determination of yields. Quasi-fixed inputs included in the study are canal, system tank, non system tank, well inside command and well outside command water sources. The major crops considered are rice, sugarcane, groundnut and cotton.

Empirical Specification

Based on the foregoing discussion of the conceptual framework, the empirical model constitutes two blocks of equations. The first block consists of 5 sets of equations describing the allocation of area to different water sources. The first block of equations can be summarized as follows :

$$NSA_i = \alpha_0 + (\text{Incentives})\ \alpha_1 + (\text{Constraints})\ \alpha_2 + (\text{Resources})\ \alpha_3 + (\text{Environment})\ \alpha_4 + u_1 \quad (27)$$

(i = 1 to 5 denote sources)

where NSA is the total net irrigated area allocated to canal, system tank, non system tank, well inside command and well outside command sources respectively. As illustrated, the allocation decisions are determined by four sets of variables ; incentives, constraints, resources and environment. The α's are coefficients to be estimated, and u's are random disturbance terms.

The second block consists of five sets of equations. Each set consists of four subset of crop area allocation equations in the respective water source. The data include gross area by crops in different sources as dependent variables. Therefore, they depend on the incentives, constraints, resources and environment. Schematically, these equations can be expressed as follows :-

$$A/S_{ij} = \beta_0 + (\text{Incentives})\,\beta_1 + (\text{Constraints})\,\beta_2 + (\text{Resources})\,\beta_3 + (\text{Environment})\,\beta_4 + u_{11} \qquad (28)$$

(i = 1 to 5 denote sources , j = 1 to 4 denote crops)

where A/S is the area allocated to crop j in canal, system tank, non system tank, well inside command and well outside command respectively. The crops selected (j) are rice, sugarcane, groundnut and cotton. The β's are coefficients to be estimated and u's are random disturbance terms. The above two blocks of equations are determined simultaneously as a system using the iterative Zellner efficient method. This system is estimated by LIMDEP package.

Definition of variables included in the first block to explain the sources are summarized.

First Block - Definition of Source Equations

Dependent Variables

1. Net canal irrigated area (hectares)
2. Net system tank irrigated area (hectares)
3. Net non-system tank irrigated area (hectares)
4. Net 'well inside command' irrigated area (hectares)
5. Net 'well outside command' irrigated area (hectares)

Independent Variables

Constraints

1. Total net irrigated area (hectares)
2. Population (numbers)
3. Number of wells

Incentives

4. Real Agricultural GDP lagged one year per capita (rupees)
5. Production index

Resources

6. Fertilizer availability (NPK-Kgs per hectare)
7. Infrastructural index

Environment

8. Mean rainfall of North east and South west monsoon (mm)
9. Mean rainfall of current and lag one year (mm)
10. Mean rainfall of lag one and lag two years (mm)

Other Variables

11. Net canal irrigated area lag one year (hectares)
12. Net system tank irrigated area lag one year (hectares)
13. Net non system irrigated area lag one year (hectares)
14. Net well inside command irrigated area lag one year (hectares)
15. Net well outside command irrigated area lag one year (hectares)

The specific variables are described in detail.

Constraints

The capital available for irrigation development is limited and it is the major constraint for the expansion of sources. The direct measure of amount available for irrigation investment is not available. As an alternative, total net irrigated area is used.

This measure is the result that is generated due to the amount utilized for irrigation development. Thus total net area irrigated of all sources measured in hectares is included as a proxy for irrigation investment. This variable would also measure the marginal share of each source if there is an increase in the total net irrigated area. Population pressure is also an important constraint adversely affecting the existing irrigation system. Population in numbers as independent variable would include the effect of foreshore encroachment, housing settlement, unauthorised cultivation and overgrazing in the catchment areas. This variable also take care of effect of physical factors such as deforestation and siltation over years. Number of well is included as explanatory variable to capture the effect of increasing wells on net irrigated area.

The per capita agricultural GDP lagged one year measured in constant prices is included as an incentive which will include the effect of private investment on irrigation. This variable also represents the use of comprehensive physical and human capital used in the development of irrigation. Lagged per capita agricultural GDP is taken to allow for time element which is involved in the irrigation investment.

The changes in the productivity and profitability of irrigated agriculture brought about by technical change are captured by the variable, production index. This variable is expressed as a composite index, with the average value of productivity of all crops and with 1960-61 serving as the base and it is the proxy variable for agricultural technology.

Resources

Inputs and infrastructures are the major measures of resource availability. Lagged total fertilizer per hectare is included as an indication of fertilizer availability. In addition to this variable, allocation of private funds to water resources development is influenced by factors like roads, railways, communications, electricity and commercial banks. Infrastructural index is calculated as discussed earlier and included in the model.

Environment

Environmental factors that affect the area allocation of sources are difficult to quantify. One environmental variable that is easy to quantify and on which data are available is rainfall. Thus, different forms of rainfall variables are defined to capture effect of environment.

Other variables

The level of irrigation investment also depends on the existing capital stock. The available stock is represented by the lagged dependent variable. Lagged source net irrigated area are included separately in their respective models. Such a decomposition allows the various components of lagged net irrigated area to have different effects on the irrigated sources.

Definition of variables included in the second block to explain crop area allocation in different source viz., canal, system tank, non-system tank, well inside command and well outside command is summarized.

Source Area Allocation Among Crops

Dependent Variables

1. Gross Rice area irrigated by source (hectares)
2. Gross Sugarcane area irrigated by source (hectares)
3. Gross Groundnut area irrigated by source (hectares)
4. Gross Cotton area irrigated by source (hectares)

Independent Variables

Constraints

1. Gross source irrigated area (hectares)

Incentives

2. Expected price of rice per ton
3. Expected price of cane per ton
4. Expected price of groundnut pods per ton
5. Expected price of lint per quintal

Resources

6. Fertilizer availability (NPK - Kgs per hectare)
7. Pesticide availability (Kgs per hectare)
8. Infrastructural index

Environment

9. Current rainfall (mm)

Other Variables

10. Gross rice area lag one year (hectares)
11. Gross sugarcane area lag one year (hectares)
12. Gross groundnut area lag one year (hectares)
13. Gross cotton area lag one year (hectares)

The specific variables that capture the effect of incentives, constraints and environment on the area allocation decisions are described below.

Incentives

The incentive measures include product and factor prices. Under uncertainity, prices are replaced by expected prices. Thus, the variables included to capture the relevant incentives for producers are product prices deflated by wage, all lagged one year. The price variables are deflated by wage to ensure that the area share equations are homogeneous of degree zero in all prices.

Constraints

The term constraint is used here to represent the available irrigation facilities that affect the implementation of technology. The decisions on area allocation are made conditional on the available land and irrigation facilities. Data on irrigation facilities at the state level are available. Therefore, gross irrigated area by source is used as a measure of the irrigation capacity available in the short run. Others have made similar assumptions in empirical studies (Schwarz 1986[5] and Evenson, 1983[6]). Each of these studies used gross cropped area and gross irrigated area as the relevant land and irrigation constraints, respectively. Their implicit assumption is that the intensity with which the land is cropped is exogenous and therefore this study measures the relevant land and irrigation constraints by sourcewise gross irrigated area available. Thus the intensity with which the land is cropped is determined endogenously. Further, a distinction is made between land irrigated by sources (wells, tanks and canals). The distinction is essential for the analysis of the response of the quasi-fixed inputs to changes in economic variables as the private and government sectors have different rules determining their investment behaviour. The gross area irrigated by sources are included in the area equations.

Resources

The expected supply of fertilizers is measured by the supply available (used) last year (measured in terms of total nutrient content per net cropped area). Obviously, lagged supply values

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[5] A.Schwarz, The Effect of High Yielding Varieties on Agricultural Labour Demand in Rural North India, Agriculture Workshop paper, University of Chicago, Chicago, 1986.

[6] R.E.Evenson, The Economics of Agricultural Growth : The Case of Northern India, Economics Seminar Paper, Colorado University, Colorado, 1983.

are independent of contemporaneous shocks in demand. No attempt was made to construct a more elaborate specification of expectations of fertilizer availability, as a strong response to increase in supply of fertilizers is captured well by the present procedure. Similarly, the expected supply of pesticide is measured by the supply available last year (kgs per hectare) and incorporated in the model.

The availability of physical infrastructure, represented here by the availability of roads, railways, telecommunications, electricity and commercial banks have a potential influence on the area allocation decisions. Specifically, the availability of roads affects the degree to which the rural areas are integrated within the market. The infrastructural index has been developed as per the procedure outlined here.

Infrastructural Index

Infrastructure is now becoming an important factor influencing agricultural supply. An attempt is made to develop an aggregate index of physical infrastructure development of the Tamil Nadu State. The physical infrastructures identified in the study are length of roads, railways, telecommunications, electricity and commercial banks. The first step is to define measure of deprivation that this state suffers in case of each of the five basic infrastructures given above. Maximum and minimum values are determined over the period of study for each of the five variables, given the actual values. The deprivation measure L_i with respect to i^{th} variable is defined as

$$L_i = \frac{\max X_i - X_i}{\max X_i - \min X_i}$$

The second step is to define an average deprivation indicator L_j. This is calculated by taking a simple average of the five indicators

$$L_j = \sum_{i=1}^{5} L_i/5$$

The third step is to measure Infrastructural Development Index as one minus the average deprivation index.

$$IDI = (1 - L_j)$$

This Infrastructural Development Index has been used in the present study.[7]

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[7]Anonymous, "Infrastructure Development in Indian States", **Productivity**, 30(3): 559-560, 1992.

Environment

Environmental factors that affect the allocation decisions include the local agronomic and climatic conditions in the particular source. These variables are difficult to quantify. One environmental variable that is easy to quantify and on which data are available is rainfall. Thus, specific rainfall variables are incorporated to capture the importance of preplanting rain on the area allocation decisions.

Estimation of Productivity by Source

The outline of source area allocation model among crops reveals the suitability of crops in canal, system tank, non system tank, well inside command and well outside command sources. Productivity analysis is now followed to estimate crop productivity by source and to measure allocative efficiency of irrigation sources in producing major irrigated crops. This analysis also would find out the type of crops to be grown in a particular source. Because yields are available only by crops and not by source, the dependent variables in the productivity models are aggregate output by crop in the irrigated agriculture. The aggregate crop output is available from statistical records published by the state department of agriculture. The aggregate output depends on composition of sourcewise irrigated acreages, chosen to produce each particular crop. The composition of sources is endogenous within the system, but it is independent of the outcome of the current production, so the crop area are predetermined by the source area allocation model earlier discussed. For these reasons, estimated sourcewise crop acreages are used as explanatory variables in the productivity model. The basic regression model is as follows :

$$Y_i = \gamma_0 + \gamma_1 \text{ canal} + \gamma_2 \text{ system tank} + \gamma_3 \text{ non system tank} + \gamma_4 \text{ well inside command} + \gamma_5 \text{ well outside command} + e_t$$

where Y_i stands for aggregate crop output that is available in the statistical records. The crop (i) selected are rice, sugarcane, groundnut and cotton as these crops are major irrigated crops. Each crop will have a separate production function. Canal denotes area of crop under canal irrigation. System tank and non system tank refer to area of crop under system tank and non system tank irrigation. Well inside and well outside denote crop area under these sources respectively. γ_0 refers to constant term and γ_1 to γ_5 are the marginal productivity of respective source. The units of measurement of marginal products are as follows:

Rice in terms of paddy tonnes per hectare

Sugarcane in terms of cane tonnes per hectare

Groundnut in terms of pods tonnes per hectare

Cotton in terms of lint quintals per hectare

Linear model explained well and this model measures the source productivity directly. This estimated production function is converted into a deterministic and probabilistic frontier function using linear programming techniques. This probabilistic function is further used to measure inter-source allocative efficiency for each crop.

Frontier Model Formulation

Ferguson (1982) defined the production function as the relationship that describes the maximum possible output for the given combination of inputs and given the technology. A production function estimated by the ordinary least-squares (OLS) method shows an average response and does not represent the frontier.[8] Farrell (1957) used a deterministic approach in which he estimated a cost frontier by using linear programming (LP), requiring all observations to lie on or above the cost frontier.[9] Aigner and Chu

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[8]C.E.Ferguson, **Microeconomic Theory**, (Illionois : Home wood Publishers, 1982).

[9]M.J.Farrell, "The Measurement of Production Efficiency", **Journal of Royal Statistical Society**, 120(2):253-290, 1957.

(1968) transformed Farrell's cost frontier into a production frontier.[10] They observed all observations to lie on or below the production frontier. Since the outliers under a deterministic approach affect the results, Timmer (1971) converted the deterministic frontier into a probabilistic frontier function. This approach deletes outlier observations or extreme observations until the estimated coefficients are stabilised.[11] Timmer's probabilistic approach is presented below and used in the study. The usual linear production function can be written as

$$Y = \gamma_0 + \gamma_1 X_1 + \gamma_2 X_2 + \gamma_3 X_3 + \gamma_4 X_4 \\ \gamma_5 X_5 + e_t \qquad (1)$$

where Y is the aggregate crop output. X_1 to X_5 are the crop area under canal, system tank, non system tank, well inside command and well outside command respectively and e_t is the random error term that contains a systematic efficiency term as well. The equation (1) can be rewritten as

$$Y_t = \sum_{i=0}^{n} \gamma_i X_{it} + e_t \qquad (2)$$

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[10] D.J. Aigner and S.F.Chu, "On Estimating the Industry Production Function", **American Economic Review**,58(5): 826-839, 1968.

[11] C.P.Timmer, "Using a Probabilistic Frontier Production Function to measure Technical Efficiency", **Journal of Political Economy**,79(7): 776-794, 1971.

where $t = 1, 2, \ldots m$ are the number of years

$i = 0, 1, 2, \ldots n$ are the number of variables

$Y_t = \hat{Y}_t + e_t$

Where one column of X_i is a vector of ones to allow for an intercept. If all error terms are constrained to one side of the estimated production surface the resulting function is an envelope. To be an efficient frontier, equation (2) can be estimated such that

$$\sum_{i=0}^{n} \gamma_i X_{it} = \hat{Y}_t \geq Y_t \qquad (3)$$

The efficient years satisfy the equality condition of $e_t = 0$ or $\hat{Y}_t = Y_t$. All other years have a smaller actual output than would be achieved if they too were efficient. To force the estimated production surface to lie as closely as possible to the actual set of output points, a minimising constraint should be placed on some function of sum of the resulting error terms. The problem then is to minimise $\sum e_t$

subject to the constraint $\hat{Y}_t \geq Y_t$ (4)

$t = 1, 2, \ldots m$ are the number of years.

This forms a linear programming problem. The production frontier in equation (4) can be transformed into a probabilistic frontier with the deletion of outliers one by one, until all coefficients are stabilised. Stabilisation can be obtained if there has been insignificant changes in coefficients in the last iteration compared with changes noted in previous iteration.

By setting all $e_t \geq 0$, equation (3) can be written as an equality.

$$\sum \gamma_i X_{it} - e_t = Y_t \tag{5}$$

The objective is to minimise

$$\sum e_t$$

subject to $\sum \gamma_i X_{it} \geq Y_t$

and $\gamma_i \geq 0$. In order to solve this problem using linear programming, $\sum e_t$ should be expressed as a linear function of Y_{it} and X_{it}. For that purpose, equation (5) can be summed over t and solved for $\sum e_t$.

$$\sum_{t=1}^{n} e_t = \sum_{t=1}^{m} \sum_{i=0}^{n} \gamma_i X_{it} - \sum_{t=1}^{n} Y_t \tag{6}$$

Where

n = number of variables (i = 0, 1, ... n)

m = number of observations (t = 1, 2, ... m)

For any particular data set, the last term in the equation (6) $[-\sum Y_t]$ is a constant. Any set of γ_i, that minimises $\sum e_t$ for one value of $-\sum Y_t$ will minimise for any other values including zero. Hence the last term $[-\sum Y_t]$ can be dropped from equation (6) without any consequence. Minimisation of sum of e_t over all years is approximately equal to the minimisation of the sum of estimated value of output.

$$\text{Min} \sum e_t \approx \text{Min} \sum \gamma_i X_{it} \tag{7}$$

For computational purpose, it is desirable to divide equation (7) by (m) number of observations.

Thus the arithmetic mean of observations of the i^{th} input $\bar{X}_i$ is used instead of total.

$$\frac{1}{m} \sum e_t = \sum \gamma_i \bar{X}_i$$

where

$$\bar{X}_i = [\frac{1}{m}] \sum X_i$$

Therefore, the objective function in equtionn (4) is altered. In expansion terms, the objective of the linear programming is to minimise

$$\gamma_0 + \gamma_1 \bar{X}_1 + \gamma_2 \bar{X}_2 + \gamma_3 \bar{X}_3 + \gamma_4 \bar{X}_4 + \gamma_5 \bar{X}_5 \tag{8}$$

subject to

$$\gamma_0 + \gamma_1 X_{11} + \gamma_2 X_{21} + \gamma_3 X_{31} + \gamma_4 X_{41} + \gamma_5 X_{51} \geq Y_1$$

$$\vdots$$

$$\gamma_0 + \gamma_1 X_{1m} + \gamma_2 X_{2m} + \gamma_3 X_{3m} + \gamma_4 X_{4m} + \gamma_5 X_{5m} \geq Y_m$$

and $\gamma_i \geq 0$. This can be solved by any linear programming package.

The vector $Y_t / \hat{Y}_t$ is the index of technical efficiency with a separate measure for each year. These measures can be averaged over number of observations to reach a single value of technical efficiency. The measure may vary from zero to one.

$$\text{Average technical efficiency (TE)} = \frac{1}{m} \frac{\sum Y_t}{\sum \hat{Y}_t} \qquad (9)$$

The overall source allocative efficiency is estimated to be

$$AE_i = \hat{Y}_t / \tilde{Y}_t \qquad (10)$$

where $\hat{Y}_t$ is the maximum possible output of the year i

$\tilde{Y}_t$ is the output at the optimum level of all sources.

The maximum possible output of the year i estimated by substituting the i^{th} year sources into probabilistic frontier function.

The specific source allocative efficiency is estimated to be

$$AE_{ji} = \hat{Y}_t / \overset{*}{Y}_t$$

where $\hat{Y}_t$ is the maximum possible output of the year i and $\overset{*}{Y}_t$ is the output at the optimum level of the j^{th} source, keeping all other sources remaining at the level at which they are used in i^{th} year.

The economic efficiency is estimated by multiplying technical and overall source allocative efficiency.

$$EE = (TE)\ (AE) \qquad (11)$$

These measures are averaged over number of years to arrive a single value of economic efficiency.

The determinants of economic efficiency are identified, measured and discussed.

DESCRIPTION OF THE STUDY AREA

CHAPTER IV

DESCRIPTION OF THE STUDY AREA

The research study carried out in an area must pertain to the needs and requirements of that area. This is particularly so in agricultural economics research. Hence a detailed knowledge on the climate, soil type, cropping pattern, socio-economic characteristics, land use pattern and agro climatic zones of Tamil Nadu is essential for the present study.

Physical features

Tamil Nadu is the southernmost State in the Indian subcontinent. It lies in the shape of a rhomboid between the Deccan Plateau and the sea, stretching from latitude 8^{o}N in the southwest at Kanyakumari, to the Pulicat lake in the northeast at 11^{o}N. The Western Ghats in the west, the Bay of Bengal in the east and the Gulf of Mannar, which separates India from Sri Lanka, in the south, constitute natural boundaries of the State on three sides. Tamil Nadu covers a little over 130,000 sq km, representing about 4 per cent of India's geographical area.

The topography of Tamil Nadu consists, broadly, of the coastal plains in the east, with uplands and hills as one proceeds westwards, with the plains accounting for a little more than half the area of the State. Hills in the western and northern portions of the State are constituted respectively by the Western and Eastern Ghats. The latter follow a southwestward course from about the latitude of Madras, forming the southern edge of the wider Deccan plateau, and meet the Western Ghats in the Nilgiris. Because of their low elevation and broken character, the Eastern Ghats have not been an obstacle to free movement from the Deccan into Tamil Nadu, a feature that has historically enabled successive incursions into the Tamil territory from kingdoms to its north.

The forest area in the State covers little more than two million hectares, accounting for about 17 per cent of the geographical area of the State, which is less than the all-India average of 22 per cent. In terms of per capita forest availability, Tamil Nadu accounts only 0.05 hectares, which is less than half of the all-India average. Forests are mainly concentrated in the Nilgiris and in the hilly tracts of North Arcot, Salem, Dharmapuri, Coimbatore, Periyar, Madurai and Tirunelveli districts.

Tamil Nadu has a number of rivers but, unlike the major rivers of Northern India, they are relatively small and entirely dependent on rainfall. The Cauvery basin accounts for nearly two-thirds of surface irrigation in the

State. Except for the Tamaraparani, the major rivers of importance to irrigation in Tamil Nadu either rise in Karnataka (Cauvery, Palar, Pennaiyar) or have been dammed and diverted from their westward flow into Kerala (Periyar, Parambikulam-Aliyar). As far as irrigation is concerned, Tamil Nadu is thus vulnerable to fluctuations in rainfall as well as dependent on inter-State cooperation for its water flows, particularly in the Cauvery.

Rainfall

All sources of irrigation in Tamil Nadu viz., canals, tanks and wells depend ultimately on rainfall for their recharge. The characteristics of rainfall i.e., quantum, seasonal pattern, spatial distribution, variability have, therefore, a vital bearing on the extent and reliability of irrigation. The normal rainfall (average of 40 years from 1951 to 1990) is about 943 mm per annum.

A distinguishing feature is that Tamil Nadu benefits from two monsoons, namely the southwest (June-September) and the northeast (October-December) which account for more than 80 per cent of the total rainfall, the northeast monsoon accounts for 47.6 per cent compared to 32.4 per cent by the southwest monsoon. The balance is accounted for by rain during the summer (15 per cent) and winter months (5 per cent).

Table 3. **Normal rainfall in Tamil Nadu**

(Centimetres)

Districts	June-Sept. (Southwest monsoon)	Oct-Dec. (Northeast monsoon)	Jan-May	Total annual rainfall
Madras	36.37	79.50	12.67	128.54
Chengleput	39.37	69.10	12.23	120.70
South Arcot	39.18	62.78	16.93	118.89
North Arcot	44.01	38.55	14.62	97.18
Salem	35.49	30.31	18.44	84.24
Dharmapuri	36.59	29.10	18.68	84.37
Coimbatore	17.92	35.17	18.34	71.43
Periyar	21.29	31.63	18.78	71.70
Trichy	27.33	39.48	17.45	84.26
Pudukottai	34.53	39.25	17.97	91.75
Tanjore	28.87	68.06	19.91	116.84
Madurai	23.32	40.90	21.26	85.48
Ramanathapuram	18.54	45.55	19.86	83.95
Tirunelveli	10.95	48.58	21.95	81.48
Kanyakumari	54.62	56.40	35.95	146.97
Nilgiris	106.13	51.36	34.59	192.08
State	30.57	44.94	18.87	94.38

Source: Government of Tamil Nadu, Agrostat, Various issues, Directorate of Agriculture, Madras.

In recent years, the extremes in the southwest monsoon have varied between a surplus or deficiency of about 40 per cent (in 1975 and 1982 respectively) while the range in the northeast monsoon was much wider, swinging between a very high deficiency of 61 per cent in 1974 and a surplus of 55 per cent in 1977. The high variability of the northeast monsoon arises from the fact that rains during this period are a function not only of the retreating currents from the southwest monsoon but, more importantly, of depressions and cyclonic storms in the Bay of Bengal. Given the generally hot climate of the State (18° to 44°C except in hill areas) evapo-transportation is high. It is estimated that, after allowing for run off and evaporation, the utilisable rainfall for the purpose of irrigation is only about 20 per cent.

Soils

The predominant soil category in Tamil Nadu is red loam, which is found in almost all the districts except Kanyakumari. Black soils, suitable for cotton cultivation, are extensively found in western Ramanathapuram, Tirunelveli, Salem, Coimbatore and Tanjore. Alluvial soils are a feature of the deltaic tracts in Tanjore, Trichy South Arcot, and parts of Tirunelveli. Sandy and salin soils are more predominant in coastal tracts.

Population

In 1991, Tamil Nadu had a population of 55.6 million, which makes it the seventh largest State in the country and somewhat similar in size to countries such as Turkey, Thailand, France and Italy. In terms of area, however, Tamil Nadu ranks 11th in the country and, consequently, it is one of the most densely populated States in India, with 428 persons per square kilometre, compared to the all-India average of 321. There has been a three fold rise in population during the last 90 years with nearly two-thirds of this increase occurring since Independence (Table 4). In the early decades, population grew by considerably less than one per cent a year largely on account of high death rates. Efforts to control births started rather late and have not yet succeeded on a scale sufficient to neutralise the effects of declining death rates. Consequently, the rate of population growth during the last three or four decades has been substantially higher than in the first three or four decades of the century.

Between 1901 and 1941 the total population of the State rose by barely 40 per cent, compared to an increase of 85 per cent in the subsequent four decades. The growth in the seventies seems to have been somewhat lower than during the sixties. The State's population is expected to rise by another 25 per cent during the next two decades and to exceed 60 million by the turn of the century.

Table 4. Population of Tamil Nadu, 1901-1991

Year	Population	Decadal change in population (per cent)
1901	19253711	-
1911	20903730	8.57
1921	21629080	3.47
1931	23471854	8.52
1941	26267318	11.91
1951	30118066	14.66
1961	33687024	11.85
1971	41199168	22.30
1981	48408077	17.50
1991	55638318	14.94

Source: Government of Tamil Nadu, Tamil Nadu:An Economic Appraisal, Various issues, Department of Statistics, Madras.

Agriculture

In the process of economic growth, the share of agriculture in the net domestic product tends to decline partly, due to the lower proportion of income spent on food as income increases (the operation of Engels's Law), and partly to the higher productivity and production in the non-agricultural sectors.

In the State, the contribution of agriculture (inclusive of crop, livestock, fisheries and forestry) to the Net State Domestic Product (NSDP) at constant prices has been undergoing a decline over the years. It has declined from 52 per cent in 1960-61 to 40 per cent in 1969-70 (constant 1960-61 prices) and from 39 per cent in 1970-71 to 29 per cent in 1981-82 (constant 1970-71 prices). While a similar structural change has taken place at the national level, the order of decline in the share of agricultural sector has been much greater in Tamil Nadu. The decline at the national level was from 49 per cent to 40 per cent during the same period. Although, in both cases the structural change is a result of the development process, the relatively greater decline in the share of the agricultural sector in Tamil Nadu has to be ascribed, also, to the lack of sustained growth in agriculture.

Although the relative share of agriculture in NSDP has declined, the occupational structure of the working population has not undergone any significant transformation over the years. The proportion of the working population dependent on agriculture (comprising of cultivators and agricultural labourers) has only marginally declined from 63.3 per cent in 1961 to 61.8 per cent in 1971 and to 60.9 per cent in 1981.

Land Utilisation

Changes in land utilisation over the decades 1960-61, 1970-71 and 1990-91 at the State as well as the all-India level are indicated in Table 5. Net area sown in the State has shown an increase, from 46 per cent of the geographical area in 1961 to 47.5 per cent in 1970-71. However, it has declined to 45 per cent in 1990-91. Year to year fluctuations in net area sown have been a noticeable feature of land utilisation in the State, due to the vagaries of the weather. Area sown more than once has also been declining since 1960-61 where it was 22.0 per cent in 1960-61, 19.7 per cent in 1970-71 and 18.8 per cent in 1990-91. The gross cropped area accounted for 53.4 per cent of the geographical area in 1990-91.

Area under forests has shown a slight increase from 14.3 per cent in 1960-61 to 15.6 per cent of the

Table 5. Land utilization pattern in Tamil Nadu

(000 hectares)

Particulars	Tamil Nadu 1960-61	Tamil Nadu 1970-71	Tamil Nadu 1990-91	All India 1990-91
I. Total geographical area (As per village papers)	13,014 (100)	13,014 (100)	12,994 (100)	304,210 (100)
II. Land Utilisation				
1. Forest	1,866 (14.3)	2,013 (15.5)	2,030 (15.6)	67,340 (22.1)
2. Barren and uncultivable land	945 (7.3)	832 (6.4)	575 (4.4)	20,310 (6.7)
3. Land put to non-agricultural uses	1,295 (9.9)	1,489 (11.4)	1,776 (13.7)	20,040 (6.6)
4. Cultivable waste	706 (5.4)	507 (3.9)	316 (2.4)	15,450 (5.1)
5. Permanent pastures and other grazing lands	363 (2.8)	231 (1.8)	151 (1.2)	12,000 (4.0)
6. Land under miscellaneous tree crops and grooves not included in net area sown	246 (1.9)	226 (1.7)	183 (1.4)	3,460 (1.1)
7. Current fallows	974 (7.5)	965 (7.4)	1,549 (11.9)	13,690 (4.5)
8. Other fallow lands	623 (4.8)	573 (4.4)	548 (4.2)	9,180 (3.0)
9. Net area sown	5,997 (46.1)	6,169 (47.5)	5,846 (45.0)	142,740 (46.9)
III. Area sown more than once	1,324	1,215	1,099	37,620
IV. Gross cropped area	7,320 (56.2)	7,384 (56.8)	6,945 (53.4)	180,360 (59.3)

Source: Government of Tamil Nadu, Tamil Nadu: An Economic Appraisal, Various Issues, Department of Statistics, Madras.

geographical area in 1990-91. Even so, the state has to go a long way before attaining the prescribed level of bringing 33.0 per cent ultimately. Cultivable waste has diminished from 5.4 per cent in 1960-61 to 3.9 per cent in 1970-71 and to 2.4 per cent in 1990-91 due to extensive cultivation. This indicates how limited is the scope, apart from multiple cropping, for bringing additional land under cultivation. Area under permanent pastures and other grazing lands has also declined from 2.8 per cent in 1960-61 to 1.2 per cent in 1990-91. This has important implications for supporting the present size of the livestock population.

Increasing urbanisation of the State is reflected by larger proportion of land diverted to non-agricultural uses (13.8 per cent in the State compared to 6.6 per cent at the all-India level). The proportion of cultivable waste is higher at the all-India level (5.1 per cent) than at the State (2.4 per cent); so also, the area under permanent pastures and other grazing lands (4.0 per cent at the all-India level as against 1.2 per cent at the State). Low per capita land availability of the state, 0.27 ha as against 0.44 ha of the country (1980-81), limits the scope for extensive cultivation in the State.

Of the net area sown in the State in 1990-91, 44.8 per cent has been irrigated compared with 27.6 per cent for the country as a whole. Nearly 56 per cent of area sown in the State depends on rainfall. Agricultural production over large tracts of the State is, therefore, susceptible to wide flucutations on account of poor and erratic rainfall.

The cropping intensity of the State was 123 per cent in 1960-61, which declined to 120 per cent in 1970-71 and 118.8 per cent in 1990-91. Of the gross cropped area, the area under foodgrains in the State has accounted for 67 per cent in 1990-91. The principal commercial crops in the state are sugarcane, groundnut and cotton which, together, accounted for 17.7 per cent of the gross cropped area (1990-91).

Cropping pattern

During the past three decades, significant changes have taken place in respect of cropping pattern (Table 6). It could be seen from the table that the dominant crop in the State has been rice. Despite, variations in the cropping pattern, it has maintained its predominance throughout the period. A major development has been the decline in area under coarse cereals, cholam, cumbu and ragi. In the fifties, the proportion of gross cropped area (GCA) under coarse cereals was of the order of 25 per cent. This proportion has started declining in the sixties and the decline was accelerated from mid-seventies. By 1980-81, the

Table 6. Percentage of Gross Cropped Area under major crops in Tamil Nadu

Crop	1960-61	1970-71	1980-81	1990-91
Rice	34.4	35.7	35.5	34.8
Cholam	10.6	10.0	9.1	11.2
Cumbu	6.7	6.4	5.0	5.0
Ragi	5.0	3.8	3.0	2.9
Toral cereals	63.9	62.5	57.2	58.7
Total pulses	5.8	6.6	8.4	8.7
Groundnut	11.9	13.3	13.0	12.8
Sugarcane	1.1	1.5	2.8	2.2
Cotton	5.4	4.0	3.4	2.7
Other crops	11.9	12.1	15.2	14.9
Total GCA in 1000 hectares	7,321	7,384	6,470	6,945

Source: Government of Tamil Nadu, Agrostat, Various issues, Directorate of Agriculture, Madras.

proportion of GCA under coarse cereals had shrunk to about 17 per cent. There has been a slight recovery since then, the proportion rising to 19 per cent in 1990-91.

In the fifties, the proportion of GCA under rice was approximately 32 per cent and in the sixties it was 37 per cent. However, in the later part of the seventies, the proportion of GCA under rice rose to 37.7 per cent. This momentum could not be sustained in subsequent years due to unfavourable seasonal conditions.

Expansion in irrigation and profitability from rice have been the major factors responsible for shift in area under coarse cereals to rice. There has been a close relationship between expansion in irrigation facilities and increase in rice acreage. It is evident that the total gross area irrigated rose from 32.4 lakh ha in 1960-61 to 34.1 lakh ha in 1970-71 and 39.8 lakh ha in 1979-80. With the expansion in irrigation facilities, the area under rice has increased to 25 lakh ha in 1979-80 (Table 7) whereas the acreage under coarse cereals has declined from 16 lakh ha in 1960-61 to 15 lakh ha in 1970-71, and to 13 lakh ha in 1979-80. Profitability from rice made the farmers to go for more area under rice after the adoption of the seed-fertilizer technology from the mid-sixties.

Table 7. Area, production and productivity of major crops in Tamil Nadu

A - Area ('000 hectares)
B - Production ('000 tonnes)
C - Productivity (kg. per hectare)

Year		Rice	Cholam	Cumbu	Ragi	Pulses	Groundnut	Sugarcane[1]	Cotton[2]
1960-61	A	2518	774	489	364	426	877	81	396
	B	3559	631	301	360	109	1057	673	374
	C	1413	815	616	989	256	1217	8454	107
1970-71	A	2636	742	475	283	491	985	114	296
	B	5007	543	312	334	133	989	1074	342
	C	1899	732	657	1180	271	1004	9430	196
1980-81	A	2299	591	328	197	544	842	183	220
	B	4279	451	264	258	175	768	1928	260
	C	1861	762	805	1314	322	912	10531	201
1990-91	A	2520	666	366	247	883	1151	192	265
	B	5394	510	434	310	348	1250	2037	575
	C	2140	976	1184	1326	394	1268	10215	360

[1] Sugarcane in terms of gur
[2] Cotton in terms of thousand bales of 170 kg lint

Source: Government of Tamil Nadu, Season and Crop Reports of Tamil Nadu for *various years*, Directorate of Agriculture, Madras.

Even under rainfed conditions, groundnut has been more profitable than cholam and cumbu which are the substitutes. The tendency, therefore, under favourable monsoon conditions, had been to put more area under groundnut and less under bajra and jowar.

As may be seen from Table 6, in 1960-61, rice accounted for 34.4 per cent of GCA and coarse cereals for 22.3 per cent, the rice/coarse cereal ratio being 1.5:1. By the late seventies this ratio had gone up to 2.2:1, a clear indication of more acreage under rice and less under coarse cereals. In the early eighties, with the decline in area under rice due to unfavourable weather conditions, the process of substitution was arrested; thus the rice /coarse cereal ratio came down to 1.8:1 in 1990-91.

There has been no perceptible tendency in the State towards substitution of pulses by more remunerative cereal crops as has taken place in the North Indian States. This has been mainly due to the fact that pulses have been largely grown in rice fallows in the State. In fact, there has been a slight increase in the proportion of pulse area to gross cropped area, from 5.8 per cent in 1960-61 to 8.4 per cent in 1980-81 and to 8.7 per cent in 1990-91.

Among non-foodgrains, sugarcane has shown a substantial increase in cropped area since 1960-61. Even so, it represents only a small proportion of GCA i.e., 1.5 per cent in 1970-71, which doubled to 2.8 per cent in 1980-81 which may be due to the increase in the number of sugar factories from 16 in 1976-77 to 21 in 1989-90. Increased demand for cane as well as the remunerative cane price fixed by the government also attracted more area under sugarcane. The acreage, however, declined slightly in subsequent years due to adverse climatic conditions.

Groundnut has been one of the major non-foodgrain crops in the State. From 12 per cent of GCA in 1960-61, the proportion of area under the crop rose to 13.3 per cent in 1970-71 and to the peak level of 14.9 per cent in the mid-seventies. Since then, the proportion has tended to decline, and, in the early eighties, it has been below 13 per cent.

The proportion of cotton acreage to GCA was slightly above 5 per cent till mid-sixties. Since then, it has been declining. In the seventies, the proportion was between 3 and 4 per cent. In the eighties there has been a shrinkage in acreage due to pests and acute drought conditions, whereas in 1990-91 the proportion to GCA had declined to 2.7 per cent.

Production and Productivity

The impressive increase in agricultural production i the fifties in the State is to be ascribed largely t extensive cultivation. This was facilitated by the increase in net irrigated area from 17.9 lakh ha in 1950-51 to 24.6 lakh ha in 1960-61, representing an increase of 37 per cent. Total gross cropped area has increased from 58.0 lakh ha in 1950-51 to 73.2 lakh ha in 1960-61. The increase in rice production in the fifties was mainly due to increase in area under cultivation. Of the increase in production of rice from 19.3 lakh tonnes in 1950-51 to 35.6 lakh tonnes in 1960-61, the area effect alone accounted for 58 per cent.

In the sixties, upto 1969-70, production of rice had been fairly stationary (35-40 lakh tonnes). A breakthrough in rice production and productivity could take place only with the adoption of the seed-fertilizer technology in the mid-sixties, though not on a large scale till 1970-71. The production of rice rose sharply from 40.1 lakh tonnes in 1969-70 to 50.0 lakh tonnes in 1970-71 and to 58.0 lakh tonnes in 1979-80.

The productivity of rice was 1413 kg per ha in 1960-61. In 1965-66, before the adoption of the new technology, the productivity was 1408 kg per ha. By 1970-71 the productivity had increased to 1899 kg per ha. In 1981-82, it was 2265 kg per ha. Next to Punjab, fertilizer consumption has been the highest in Tamil Nadu (67 kg per ha). The details of fertilizer and pesticides consumption in Tamil Nadu are presented in Table 8.

Table 8. Fertilizers and pesticides consumption in Tamil Nadu

('000 tonnes)

Year	NPK	Nitrogen	Pesticides
1960-61	126.84	61.03	0.95
1961-62	130.65	61.84	1.13
1962-63	134.57	63.69	1.09
1963-64	138.61	65.57	1.21
1964-65	142.76	72.13	1.33
1965-66	147.05	79.34	1.58
1966-67	151.46	87.27	1.89
1967-68	156.02	96.14	2.30
1968-69	155.23	104.07	2.15
1969-70	223.35	147.87	2.27
1970-71	296.64	172.87	2.73
1971-72	347.16	214.48	2.19
1972-73	279.80	179.25	2.76
1973-74	327.42	185.42	3.50
1974-75	272.07	147.98	4.13
1975-76	285.90	199.64	4.78
1976-77	281.46	184.19	4.03
1977-78	424.68	265.74	4.39
1978-79	492.93	305.87	4.13
1979-80	537.94	324.62	3.87
1980-81	491.30	292.41	4.95
1981-82	512.63	313.34	5.17
1982-83	465.40	266.87	5.49
1983-84	586.78	337.12	6.05
1984-85	690.57	393.88	6.17
1985-86	668.29	378.93	6.23
1986-87	674.41	384.81	6.35
1987-88	683.73	367.70	6.29
1988-89	698.43	416.30	6.97
1989-90	687.94	400.10	7.68

Source: *Government of Tamil Nadu*, Agrostat, Various issues, Directorate of Agriculture, Madras.

Sources of growth

The most important factor accounting for the marked increase in production has been the adoption of high yielding fertilizer-responsive rice varieties such as IR 8, IR 20, IR 22 and IR 50. The rice area covered by HYVs rose from 1.9 lakh ha in 1966-67 to about 18.0 lakh ha in 1970-71 and to 23.6 lakh ha in 1979-80, covering 81.2 per cent of total rice area. By 1990-91, the proportion of rice area covered by HYVs had gone up to 94 per cent.

The rapid adoption of the new seed varieties was facilitated by three factors, the expansion of irrigation, the use of fertilizers and pesticides. There has been a remarkable expansion in area irrigated by wells which went up from 566 thousand ha in 1960-61 to 1,174 thousand ha in 1979-80, representing an increase of 36.6 per cent and 51.8 per cent, respectively. It may be noted that the emphasis in the seventies was on private irrigation which has also been referred to as Tamil Nadu's pumpset revolution.

Extensive use of HYVs made the consumption of fertilizers manifold. Although data on fertilizers applied to foodgrains are not available separately, 75 per cent of fertilizer consumption is conveniently ascribed to foodgrains, rice acccunting for the bulk of the consumption. Fertilizer applied to foodgrains increased from 1.4 lakh tonnes in 1968-69 to 4.1 lakh tonnes in 1979-80, representing a nearly three fold increase.

Along with the adoption of HYVs, tractorisation has also been making rapid strides. The number of tractors was very low, just 327 in 1951. By 1961, it had risen to 934, an almost threefold increase. There was an impressive increase in the mid-sixties and late seventies. By 1982, the number of tractors had gone upto 16,780 representing an 18 times increase over the 1961 level. This level of tractorisation is equivalent to one tractor for 411 ha of gross cropped area. Among the districts which are prominent in their share of total tractors in the State are South Arcot, Chenglepu t, Tanjore, Salem and Coimbatore.

Although as much as about 60 per cent of gross cropped area in Tamil Nadu is unirrigated, the State compares rather well with other States in India with regard to the extent of irrigation. In the late 1970s, the ratio of gross area irrigated to gross sown area was 42.0 per cent in Tamil Nadu as compared to the all-India average of 25.8 per cent.

Rice has remained as the dominant crop among the irrigated crops in Tamil Nadu, accounting for 67 per cent of gross irrigated area in the late 1970s. The extension of irrigation, in the 1960s, 1970s and 1980s, has resulted in a shift from dry cereals to rice, but a substantial portion of the additional area brought under irrigation, has been devoted to commercial crops such as sugarcane, cotton, oilseeds, chillies, fruits and vegetables. This is related to the fact that in these two decades it is well irrigation that has been in the vanguard. The relatively well-intensive districts are also the ones in which irrigated commercial crops, such as sugarcane (Coimbatore, Periyar, North Arcot, South Arcot, Salem and Trichy), groundnut (North Arcot, South Arcot, Coimbatore and Chengleput), Cotton (Coimbatore and Madurai), and fruits, vegetables and spices (Ramanathapuram, Madurai, Tirunelveli, Coimbatore, Periyar and Trichy) are prominent.

RESULTS AND DISCUSSION

CHAPTER V

RESULTS AND DISCUSSION

The results along with discussion are furnished under the following heads in the light of the objectives of the study.

1. Analysis of irrigation development in Tamil Nadu
2. Performance of irrigation sources
3. Sourcewise area allocation among crops
4. Estimation of productivity of crops by source
5. Measurement of economic efficiency

Analysis of Irrigation Development in Tamil Nadu

Irrigation is vital to the Tamil Nadu economy as it helps to relieve agriculture from dry and rainfed conditions. The characteristics of rainfall pattern in Tamil Nadu have a crucial bearing on the extent and reliability of irrigation. All the sources of irrigation in the state viz., canals, tanks and well depend heavily on rainfall for their replenishment. Out of an average annual availability of 12.32 million hectare meters (mhm) from rainfall in Tamil Nadu, it is estimated that surface runoff, evaporation and deep percolation account for 6.25 mhm. Allowing for other constraints relating to time and place of rain, the utilisable potential had been estimated at 2.50 mhm (Sivanappan and Palanisami, 1982).[1]

In the late eighties, the ratio of gross irrigated area to gross sown area was 47 per cent in Tamil Nadu as compared to the all India average of 35 per cent. Though the growth in the extent of irrigation in terms of net irrigated area had been varying between periods, certain broad conclusions could be made (Table 9). The area under canal irrigation had stagnated and tank irrigated area had declined, while there has been a striking increase in area under well irrigation. Wells now contribute to nearly 45 per cent of net irrigated area as compared to about 24 per cent in the 1950s. The net area irrigated by tank was about 37 per cent in 1960's and it had declined to 20 per cent in 1990's. The canals has accounted for about 37 per cent in 1960's and it has been reduced to 34 per cent in 1990's, though there is a marginal increase in area under canals in absolute terms.

Growth in the extent of irrigation in terms of the proportion of net/gross irrigated area to net/gross sown area from 1950 to 1990 is given in Table 10. The large

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[1] R.K.Sivanappan and K.Palanisami, Demand for Water in Tamil Nadu in 2000 AD - Future Focus and Policy Issues, Final Report, Tamil Nadu Agricultural University, Coimbatore, 1982.

Table 9. Average net area irrigated in Tamil Nadu

('000 hectares)

Years	Sources of Irrigation				Total
	Canal	Tank	Well	Others	
1950s (1950-59)	795 (37.57)	778 (36.78)	497 (23.48)	46 (2.17)	2116 (100.00)
1960s (1960-69)	883 (35.62)	912 (36.79)	645 (26.02)	39 (1.57)	2479 (100.00)
1970s (1970-79)	894 (33.16)	849 (31.49)	918 (34.05)	35 (1.30)	2696 (100.00)
1980s (1980-89)	848 (33.27)	673 (26.40)	1006 (39.47)	22 (0.86)	2549 (100.00)
1990s (1990-93)	811 (34.13)	479 (20.16)	1071 (45.08)	15 (0.63)	2376 (100.00)

Figures in parentheses are percentages to total

Source: Government of Tamil Nadu, Season and Crop Reports, Various years, Directorate of Agriculture, Madras.

Table 10. Intensity of irrigation in Tamil Nadu (1950-1990)

(Per cent)

Years	Net area irrigated to net sown area	Gross area irrigated to gross sown area	Gross irrigated area to net irri-gated area	Gross sown area to net sown area
1950s (1950-59)	36.9	39.0	117.0	108.3
1960s (1960-69)	40.8	44.9	130.1	112.5
1970s (1970-79)	43.8	45.1	125.0	107.2
1980s (1980-89)	44.2	47.1	131.7	109.1
1990s (1990-93)	43.0	43.6	123.0	104.7

Source: Government of Tamil Nadu, Season and Crop Reports, Various years, Directorate of Agriculture, Madras.

increase in the extent of irrigation in terms of ratio of net/gross irrigated area to net/gross sown area had taken place in 1960's. The ratio had remained stagnant until 1970's, but had moved up in 1980's. The first period of growth might be associated with increases in surface irrigation viz., canals and tanks. The second period might be due to ground water development. The intensity of irrigation also reflects the same pattern. The intensity of irrigation had tangiably improved in the 1960's but has tended to decline in 1970's and thereafter improved. Functional relationship between irrigation intensity and sourcewise area irrigated and rainfall is analysed through linear multiple regression model over the period from 1960-61 to 1989-90. The estimated regression equation is :

$$IR = \underset{(1.4583)}{-6.1742} + \underset{(3.4157)}{1.2683^{**}}\ NC + \underset{(2.8706)}{1.1432^{**}}\ NT + \underset{(4.7852)}{1.3209^{**}}\ NW + \underset{(3.2109)}{0.0075^{**}}\ RF$$

$R^2 = 0.7692$ $F = 20.8297^{**}$

$N = 30$

Figures in parentheses are t statistics

** Significant at one per cent level

where,

IR = Intensity of irrigation (gross to net irrigated area)

NC = Net irrigated area of canal, expressed as percentage of total net irrigated area,

NT = Net irrigated area of tank, expressed as percentage of total net irrigated area,

NW = Net irrigated area of well, expressed as percentage of total net irrigated area and

RF = Rainfall in mm.

The results has shown that all the three source has contributed to the irrigation intensity and well irrigation comparatively has the maximum effect on irrigation intensity. This might be due to larger increase in irrigated area under well irrigation over years, protective role and conjunctive use of well water with other sources. The rainfall variable had the expected sign and was statistically significant. It was found that the relationship between rainfall and irrigation intensity was positive indicating that the intensity would raise by about 0.07 per cent for every increase in rainfall by 10 mm. This could be further confirmed by the following discussions (Table 11).

During the eighties, the four years viz., 1980-81, 1982-83, 1986-87 and 1988-89 had witnessed deficit rainfall. The deficit rainfall had caused total net area irrigated to go down during eighties (Figure 1). Net area irrigated by tanks has been affected much since more than 85 per cent of the tanks are non-system tanks depending only on rainfall run-off for tank storages. Wells were the least affected

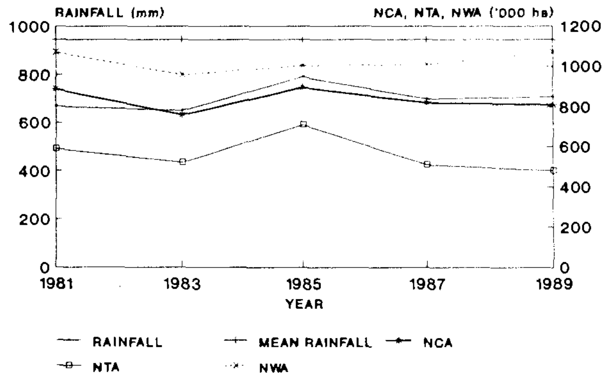
Table 11. Impact of deficit rainfall on net area irrigated

Year	Rainfall (in mm.)	Net area irrigated (million hectares)			
		Canals	Tanks	Wells	Total
1980-81	669.3 (-29.17)	0.89 (-4.72)	0.59 (-34.15)	1.07 (-4.48)	2.55 (-13.87)
1982-83	652.6 (-30.94)	0.76 (-15.21)	0.52 (-29.95)	0.96 (-8.23)	2.24 (-16.76)
1986-87	700.9 (25.8)	0.82 (5.81)	0.51 (-24.11)	1.01 (-1.94)	2.34 (-5.80)
1988-89	708.8 (-24.9)	0.81 (12.34)	0.48 (-21.48)	1.07 (-1.92)	2.36 (-2.63)

Source: Government of Tamil Nadu, Season and Crop Reports, Various years, Directorate of Agriculture, Madras.

Figures in parentheses: in the rainfall column indicate deviations in rainfall with reference to normal rainfall. In the irrigation sources, net area irrigated in that year to the previous year.

FIGURE.1. IMPACT OF DEFICIT RAINFALL ON NET AREA IRRIGATED



NCA : NET CANAL AREA; NTA: NET TANK AREA
NWA : NET WELL AREA

among the three sources because of time lag involved in the recharge of ground water. Since catchment area of major reservoirs lie in the western ghats which extend along the western border of Tamil Nadu, the impact of deficit rainfall on canal irrigated area has been only moderate. Also several reservoirs such as Parambikulam Aliyar and Lower Bhavani Projects have not been irrigating the entire command area in a single year and the impact of the deficit rainfall in a single year could not be captured fully.

a) **Analysis of canal irrigated area**

The extent of gross irrigated area under canal is more or less stagnant from 1960-1990. The compound growth rate over this period is estimated at -0.08 per cent per year. It could also be compared with marginal increase in the net canal irrigated area. The net area irrigated by canals has been subject to frequent and wide fluctuations during the past decade where it has been ranging from being 0.72 million hectares (1987-88) to 0.89 million hectares (1984-85).

In canal irrigation, the Cauvery basin alone accounts for the lion's share of nearly 64 per cent followed by Periyar Vaigai and Parambikulam Aliyar Projects with the contribution of 9 per cent each. Other smaller basins such as Palar, Pennaiyar, Vellar and Tamraparani add upto 18 per cent. Canal water resources have been intensively utilized in Tamil Nadu over a long period of time, particularly in Cauvery basin. The reasons for the stagnation in the canal source are the interstate river issues, such as sharing of Cauvery water between Tamil Nadu and Karnataka, which affect particularly the area under rice. Further non-availability of potential sites, for new investment, longer gestation periods, cost escalation with limited capital under utilization of the developed potential and rainfall variation which resulted in reduced inflows into the reservoirs.

Further several other factors contributed for the declining trend in canal irrigated area over years. Mainly (i) inclusion of elevated upland in the project area; (ii) conversion of ayacuts for non-agricultural purposes; (iii) changes in cropping pattern on account of the farmers preferences which led to increased use of water; (iv) inefficient conveyance systems below the sluice point which have lost their original size and shape resulting in heavy transmission losses; (v) absence of field boothies; (vi) excessive drawal of water in the upper reaches; (vii) unauthorised irrigation, particularly associated with indirect ayacuts and canal pumping; (viii) poor maintenance of canals resulting in seepage losses and (ix) lack of farmers' organisation at sluice level for efficient water distribution.

One of the significant changes that had taken place in the canal irrigation over the last three decades had been the changes in area under major crops. Table 12 indicates the share of gross irrigated area under major crops from 1960-90. It could be seen that the dominant crop under the canal irrigation has been rice. Despite declining in absolute area, rice has maintained its predominance throughout the period. The rice area has been declining at 0.19 per cent per year over the period. A major development has been the increase in area under sugarcane and groundnut. The sugarcane area has been increasing at 2.31 per cent per year over the period. The groundnut area has moved upward in the order of 2.15 per cent per year. However, cotton area has been stagnated in the canal system. A clear indication of more acreage coming under rice in late 1960s and early 1970s was mainly due to the modern rice technology which is compliment with canal water. The decline in area under rice in 1980s might be due to low remunerative prices for rice and unfavourable weather conditions in the eighties. With the expansion of irrigation, the tendency of farmer has been to replace low value crops by substituting high value crops like sugarcane, groundnut etc. Groundnut has shown substantial increase in eighties due to special attention given to oilseeds. Among commercial crops, sugarcane has shown substantial increase in cropped area

Table 12. Gross canal irrigated area in Tamil Nadu

(Hectares)

Year	Rice		Sugarcane		Groundnut		Cotton		All crops
	Area	Per cent	Area	Per cent	Area	Per cent	Area	Per cent	Area
1960-61	949645	90.84	11216	1.07	19899	1.90	17529	1.68	1045444
1961-62	918988	92.02	10455	1.05	20874	2.09	16843	1.69	998681
1962-63	1071680	90.48	8529	0.72	23311	1.97	21361	1.80	1184425
1963-64	937083	82.20	10106	0.89	23079	2.02	20123	1.77	1140015
1964-65	996918	91.82	12108	1.12	20553	1.89	17892	1.65	1085759
1965-66	846439	89.90	14110	1.50	22905	2.44	15663	1.66	941523
1966-67	1101541	94.06	14051	1.20	30714	2.62	17538	1.50	1171059
1967-68	1035359	88.81	14976	1.28	36231	3.11	15556	1.33	1165831
1968-69	941240	84.29	19168	1.72	27974	2.51	16327	1.46	1116665
1969-70	1028398	88.78	21605	1.87	28691	2.48	15379	1.33	1158381
1970-71	1015431	84.04	15919	1.32	36147	2.99	15326	1.27	1208333
1971-72	1072211	86.90	27862	2.26	42480	3.44	21941	1.78	1233919
1972-73	1029359	85.73	28678	2.39	44644	3.72	19369	1.61	1200629
1973-74	972103	82.92	37199	3.17	67354	3.74	19647	1.68	1172402
1974-75	747235	85.17	22411	2.55	34201	3.90	17911	2.04	877330
1975-76	991556	89.73	17895	1.62	32614	2.95	12978	1.17	1105041
1976-77	743794	85.73	21549	2.48	28739	3.31	16078	1.85	867628
1977-78	1009516	84.05	33365	2.78	49632	4.13	26504	2.21	1201040
1978-79	1049242	90.56	27137	2.34	53084	4.58	26102	2.25	1158612
1979-80	1088967	87.02	20909	1.67	56536	4.52	25699	2.05	1251421
1980-81	932545	83.55	28599	2.56	57760	5.17	20088	1.80	1116183
1981-82	965709	85.79	28934	2.57	45237	4.02	17303	1.54	1125608
1982-83	775448	84.30	29556	3.21	39572	4.30	14179	1.54	919903
1983-84	915303	87.18	21874	2.08	48055	4.58	15238	1.45	1049924
1984-85	1006201	82.97	40661	3.35	60582	5.00	23290	1.92	1212716
1985-86	824403	84.28	26725	2.73	52492	5.37	22840	2.34	978130
1986-87	776173	82.51	31418	3.34	49444	5.26	14559	1.55	970755
1987-88	766362	79.96	66187	6.91	31120	3.25	21042	2.20	958418
1988-89	745200	80.46	34720	3.75	51412	5.55	20997	2.27	926207
1989-90	725142	79.92	31122	3.43	54665	6.02	20163	2.22	907330

Source: Government of Tamil Nadu, Season and Crop Reports, Various years, Directorate of Agriculture, Madras.

since 1960-61. It represented only a small proportion of canal area, i.e., one per cent in 1960-61, two per cent in 1971-72 and to about three per cent in 1982-83. The increase in the number of sugar factories from 16 in 1971-72 to 21 in 1981-82 and the consequent increased demand for cane as well as the remunerative cane prices (Rs.150 per tonne in 1971 to Rs.525 per tonne in 1992) fixed by the government has been the major factors responsible for this development. Area under cotton has decreased from 17529 hectares in 1960-61 to 15326 hectares in 1970-71. It has increased to 20088 hectares in 1980-81 and 20163 hectares in 1989-90. The stagnation in the cotton area has been mainly due to the development of water logging and salinity in the canal system, problems of pest and diseases and fluctuations in prices.

b) Analysis of tank irrigated area

Tamil Nadu is one of the states in India where tank irrigation is very prominent. The state has 39200 tanks with varying sizes and types and accounts for about 17 per cent of the tanks in the country. It is observed that there has been a secular decline in the area under tank irrigation in 1950-90, where the area irrigated has declined from 38 per cent in 1950 to 34 per cent in 1990 (Table 9). The poor performance of the tanks might be due to socio-economic, technological and administrative factors. The socio-economic problems relate mainly to extensive encroachments in the catchments and foreshore areas, fragmentation of holdings which constrained the proper alignment of the field channels for better water distribution, lack of institutional arrangement for the equitable distribution of water, increase in population density resulting in encroachment of the tank beds for settlement and government taking over of tanks close to towns for expansion of the cities. Technological issuses relate to secular shift in the seasonal distribution of rainfall, poor run-off structures, sluices and siltation due to poor catchment treatment which might have affected the tank storges. Bunds are often weak and liable to breach at times of heavy rainfall. The prime administrative problem was inadequate financial allocation to enable systematic maintenance of tanks. The growth rate in gross tank irrigated area has been estimated at -1.49 per cent between 1960 and 1990. This could also be compared with declining net tank area at the rate of 1.17 per cent.

To study the effects of major influencing variables on tank irrigated area a functional relationship was established, wherein the gross tank irrigated area calculated by multiplying net tank irrigated area by tank irrigation intensity of the district has been a function of population pressure, seasonal rainfall (North-east monsoon and South-west monsoon) and other variables such as desiltation, soil erosion and deforestation which are related to time and are attributable to changes in the environment over years. Time as an independent variable would take care of physical factors such as soil conservation measures, technology, deforestation and siltation over years.

Population as independent variable would incorporate the effect of foreshore encroachment, settlement, unauthorised cultivation and over grazing in the catchment areas. Rainfall during North-east monsoon (October to December) and South-west monsoon (June to September) could also affect the area irrigated. The following multiple linear regression model has been specified to explain the factors affecting gross tank irrigated area.

$$A_t = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + U$$

where, A_t = Gross tank irrigated area in hectares

x_1 = Time in number of years 1961 = 1 to 1990 = 30

x_2 = North-east monsoon rainfall in mm (October, November and December)

x_3 = South-west monsoon rainfall in mm (June, July, August and September)

x_4 = Population of Tamil Nadu in numbers

a = Constant term

b_1, b_2, b_3, b_4 are parameters to be estimated

U = Error term

Further, two functions were specified based on the intensity of tank irrigation. Accordingly tank intensive districts are those where the ratio of gross tank area to net tank irrigated area is greater than one. The tank intensive districts are Chengleput, South Arcot, North Arcot, Madurai, Ramanathapuram, and Tirunelveli. For non-tank intensive districts, the ratio of gross tank irrigated area to net tank irrigated area is one or less than one. The non tank intensive districts are Salem, Dharmapuri, Coimbatore, Trichy, Tanjore, Nilgiri, Kanyakumari and Pudukottai.

The model is run by ordinary least square (OLS) method. The results of the linear regressions are presented in Table 13. In terms of prior expectations, explanatory variables in these models had expected signs. The R^2 values were significant. For the tank intensive districts, based on the criteria, all the selected variables were significant. Time, north-east monsoon rainfall and south-west rainfall had positive sign. Positive sign for time indicated that soil conservation measures in the catchment and possible regular maintenance of the tanks were practised in tank intensive districts. Population had a negative

Table 13. Regression model for tank intensive and non-intensive districts

Districts		Constant	Time	North-east monsoon	South-west monsoon	Population	R^2	F
Tank intensive							0.67	76.21
	b	394369.9289	3959.6940	54.4708	114.5142	-0.1073		
	SE	23397.1438	613.9719	15.5996	19.3333	0.0076		
	t	16.8554	6.4490	3.4920	5.9230	-14.1110		
Tank non-intensive							0.41	33.36
	b	49428.6501	-545.1019	6.4484	37.1669	-0.0035		
	SE	8771.6235	244.9605	8.8471	8.3598	0.0016		
	t	5.6351	-2.2250	0.7290	4.4460	-2.1920		

influence on gross tank area and it might be due to foreshore encroachment and unauthorised cultivation in these districts.

Holding all other variables constant, the gross tank area would increase at the rate of 3960 hectares per year in tank intensive districts and it would decrease by 545 hectares per annum in tank non-intensive districts. Less dependency on tanks, encroachment and siltation due to poor management had affected the tank area in non-intensive districts. The gross tank area was found to decrease by 0.1073 hectares and by 0.0035 hectares respectively in intensive and non-intensive districts as for every increase in population by one person. The result implied that the tank irrigated area would decrease with an increase in population density. With respect to rainfall, keeping other things constant, the gross tank area was estimated to increase at the rate of 115 hectares and 37 hectares per mm of additional rainfall during north east monsoon in intensive and non-intensive districts respectively. By the same token, the gross tank area was found to increase by 54 hectares and 6 hectares, respectively in intensive and non-intensive districts per mm of rainfall in South-west monsoon. The analysis has shown that the rainfall in general has shifted the tank irrigated area upward and its impact has been higher in tank intensive districts in both the seasons, compared to tank non-intensive districts.

For tank non-intensive districts, based on the criteria, time and population had significant but negative effects. Deforestation, lack of soil conservation and siltation over years reduced the storage capacity of the tanks causing decrease in gross tank area. As expected, the encroachment, grazing and unauthorised cultivation were higher in tanks of non-intensive districts due to poor storage capacity and poor maintenance. This might be attributed to the negative sign for the population variable.

To get more insight into the factors influencing tank performance, further analysis was carried out. The model used in the study is as follows.

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_7 + b_8x_8 + b_9x_9 + b_{10}x_{10} + U$$

Where,

Y = Actual utilization measured as the ratio of the average actual command area irrigated for five years (1985 through 1989) to the registered command

x_1 = Length of the bund in metres

x_2 = Storage capacity of the tank in million cubic metres

X_3 = Number of upper sluices in the tank

X_4 = Proportion of small farmers to the total farmers in the tank command area

x_5 = Condition of the bund (1 if good, 0 if bad)

X_6 = Water spread area of the tank in hectares

X_7 = Number of private wells per 10 hectares of command area

X_8 = Total number of farmers (pattadars) in the tank command area

X_9 = Registered command area of the tank in hectares

X_{10} = Average expenditure on tanks in rupees per hectare during the last five years (1985 through 1989)

a = Constant term

U = Error term

b_1 to b_{10} are the parameters to be estimated.

Defining the dependent variable, tank performance in terms of actual utilization (i.e., ratio of actual command area irrigated to the registered command area), and tank bund length, tank storage capacity, number of upper sluices, small farmers proportion, bund condition, water spread area, number of wells in the command, total number of farms, registered command area and average maintenance costs were considered as independent variables. The model is run using ordinary least squares (OLS) technique, by (i) combining all the sample tanks, (ii) grouping them based on tank type (system and non-system) and (iii) management type (Panchayat Union and Public Works Department tanks).

In the combined tank equation, water spread area, bund condition, upper sluice number, numbers of wells in the command area, operation and maintenance expenditure and storage capacity of the tank were significant (Table 14). As expected, storage capacity, bund condition and wells had positive sign. The negative sign for upper sluices had indicated that upper sluices had reduced the tank area since the tanks were not always full and these sluices were comparatively in higher level to draw adequate water to the canal area. When the tank water drawal was continuous, the upper sluices first used to draw the available supplies in the first month and were non-functional in the remaining periods of the rice season due to siltation of the upper sluices. Further, the upper sluices could irrigate only half of the area compared to lower sluices and the area irrigated by the upper sluices would be much affected due to water shortages as the upper sluices were comparatively in elevated positions.

Water spread area had negative sign and this was because if the water spread area of a tank increases, mostly the tail enders of the upper tank encroach this fertile part of the land for unauthorized cultivation. So, larger the water spread, higher will be the encroachment level. Further due to siltation, the water spread area actually spreads the available water very thinly over the entire area and could not be easily drawn by the sluices besides making

Table 14. Regression analysis on factors influencing tank irrigation performance in Tamil Nadu

Category	Co-efficients of the variables											R^2	F	N
	Constant	Bund length	Storage capacity	Upper sluice	Small farmers proportion	Bund condition	Water spread area	Wells	Total number of farms	Registered command area	Operation & maintenance cost			
All tanks	17.553 (2.154)	0.118 (1.354)	8.320* (1.706)	-2.349** (-2.275)	0.167 (1.485)	7.903*** (3.385)	-0.257*** (-4.270)	1.426** (2.219)	-0.005 (-0.564)	0.009 (0.548)	-0.002* (-1.892)	0.57	18.09	200
Panchayat Union Tanks	30.486 (1.752)	0.188 (1.611)	18.126** (2.292)	-3.099** (-2.049)	0.065 (0.275)	10.447*** (2.633)	-0.230** (-2.433)	1.503 (1.617)	-0.006 (-0.412)	0.012 (0.333)	-0.003** (-2.061)	0.44	14.30	105
Public Works Dept. Tanks	23.162 (2.803)	0.073 (0.412)	7.887 (1.385)	-0.026 (-0.019)	0.037 (0.302)	2.641 (1.020)	-0.283*** (-4.006)	1.313 (1.356)	-0.006 (-0.468)	0.007 (0.365)	-0.001 (-0.772)	0.50	15.00	95
Non-system Tanks	27.447 (1.575)	0.177 (1.066)	12.615 (0.897)	-2.804* (-1.801)	0.075 (0.314)	9.778** (2.340)	-0.024 (-0.127)	1.164 (1.079)	-0.006 (-0.466)	0.015 (0.398)	-0.003 (-1.310)	0.41	14.13	120
System Tanks	21.835 (2.477)	0.366** (2.314)	4.080 (0.875)	-1.298 (-0.893)	0.172 (1.329)	4.684* (1.712)	-0.340*** (-5.769)	1.766* (1.913)	-0.004 (-0.278)	0.015 (0.640)	-0.001 (-0.931)	0.52	15.41	80

Figures in parentheses indicate t statistics
* Significant at 10 per cent level of probability; ** Significant at 5 per cent level of probability
*** Significant at 1 per cent level of probability

evaporation losses higher. The Social Forestry was also much attracted by the large water spread area. For example, on an average, about 640 trees are planted per every hectare of the water spread area with 2.5 m x 2.5 m spacing.

The negative sign for operation and maintenance expenditure was unexpected. Since the investment was normally deferred investment, that too invested on a cyclic basis, actual needs are not necessarily match the investment cycle, as the Public Works Department used to invest on tanks based on the availability of funds and on priority/cyclic basis. This priority means only tanks with very bad structures such as broken sluices/weirs/bunds used to get priority. This was also true to Panchayat Union tanks which have more tanks under their control. Further, the investments were made in the non-tank irrigation period, the investment might not be actually related to benefits in a particular tank irrigation year.

Panchayat Union Tanks Vs Public Works Department Tanks

The regression analysis done for panchayat union tanks had a significant coefficients for variables such as bund condition, water spread area, storage capacity, operation and maintenance expenditure and the number of upper sluices. It was interesting to note that no variable below the outlet was significant as below outlet factors might be homogeneous in nature in Panchayat Union tanks. The negative sign of the variables viz., upper sluices and operation and maintenance cost were same as for combined tanks.

As regards to the Public Works Department tanks, only water spread area had the significant coefficient. Here also the negative sign was on par with the functions fitted for Panchayat Union tanks as well as for combined tanks. Since the Public Works Department tanks could accommodate social forestry, due to its vast water spread area, its effect on siltation etc., should have contributed for lower tank performance. Also higher the water spread area, lower will be the storage due to more evaporation and seepage losses. In several cases, higher water spread area attracted encroachers, who illegally and to drain the tank water to avoid submergence of their crops in the tank foreshore.

System tanks Vs Non-system tanks

In the case of non-system tanks, variables, viz., upper sluices and bund condition had significant coefficient. In most of the non-system tanks, bund condition was very bad due to cutting of the trees as well as using the bunds as cart-path by the farmers for transport of tank silts. In several cases, the bunds were too low to allow the bullock cart to cross the bunds from the water spread area. Thus in normal tank filling years, the tanks would be holding only less water.

For system tanks, variables above the outlet and below the outlet were significant. The coefficient for number of wells was significant which was unexpected and might be due to the method classification of system and non-system tanks. For example, in the case of system tanks, whose classification is based on their location in river basins, most of the years when the river was dry, the tanks were also dry. In the case of classification of tanks based on their location below the reservoir system, the filling of tanks are not uniform hence most of the tanks behaved as non-system tanks. For example, in Pilavakkal dam, in Kamarajar district out of 37 tanks in the chain of system only 11 tanks used to receive water from the reservoir. Since there was no separate channels to carry water from one tank to other, most of the tanks might have behaved as non-system tanks.

Table 15 indicates the area under major crops in tank irrigation. Rice area has been growing at a rate of 0.02 per cent per year and in all the years rice dominated other crops in the tank command area. Sugarcane area has been increasing at 1.25 per cent per year over the period of the

Table 15. **Gross tank irrigated area in Tamil Nadu**

(Hectares)

Year	Rice		Sugarcane		Groundnut		Cotton		All crops
	Area	Per cent	Area	Per cent	Area	Per cent	Area	Per cent	Area
1960-61	649578	68.58	31884	3.37	39290	4.15	31952	3.37	947123
1961-62	653801	76.13	20162	2.35	28180	3.28	18956	2.21	858759
1962-63	554584	75.32	14129	1.92	27932	3.79	17119	2.33	736269
1963-64	666676	72.79	19489	2.13	31156	3.40	23477	2.56	915848
1964-65	681912	67.85	34421	3.42	40582	4.04	32614	3.25	1005041
1965-66	791770	75.67	27868	2.66	37259	3.56	21205	2.03	1046324
1966-67	570037	63.55	23278	2.60	36800	4.10	13910	1.55	896975
1967-68	685294	74.07	28882	3.12	48912	5.29	18148	1.96	925190
1968-69	487083	63.29	31754	4.13	33518	4.36	13085	1.70	769613
1969-70	532186	71.52	35792	4.81	34377	4.62	12325	1.66	744086
1970-71	672105	69.22	30702	3.16	48799	5.03	17881	1.84	970982
1971-72	683264	74.18	43905	4.77	54519	5.92	25597	2.78	921090
1972-73	831749	73.65	47328	4.19	57102	5.06	29904	2.65	1129314
1973-74	785485	65.40	61390	5.11	86149	7.17	30332	2.53	1201128
1974-75	698974	69.35	44262	4.39	45508	4.52	24150	2.40	1007912
1975-76	678245	68.15	50874	5.11	64397	6.47	23656	2.38	995296
1976-77	695597	69.61	42560	4.26	46638	4.67	21688	2.17	999219
1977-78	815898	71.10	55061	4.80	63502	5.53	40922	3.57	1147389
1978-79	818931	71.36	49186	4.29	73879	6.40	36879	3.21	1145749
1979-80	822054	71.62	43312	3.77	83297	7.26	32837	2.86	1147760
1980-81	482700	63.75	47369	6.26	69225	9.14	16103	2.13	757189
1981-82	639355	71.59	55801	6.25	61071	6.84	20187	2.26	893017
1982-83	415722	66.98	44336	7.14	47109	7.59	24374	3.93	620685
1983-84	626120	64.21	62186	6.38	94874	9.73	27777	2.85	975148
1984-85	641303	71.17	45744	5.08	77762	8.63	29888	3.32	901069
1985-86	586427	67.50	51541	5.93	70863	8.16	26647	3.07	868729
1986-87	416111	65.39	47128	7.41	58861	9.25	14759	2.32	636340
1987-88	410851	57.61	78795	11.05	46681	6.55	21330	2.99	713098
1988-89	399386	62.47	52080	8.15	61204	9.57	21278	3.33	639336
1989-90	584767	60.62	61465	6.37	88721	9.20	27299	2.83	964690

Source: Government of Tamil Nadu, Season and Crop Reports, Various years, Directorate of Agriculture, Madras.

study. Increased demand for sugar, the increase in the number of sugar factories and the remunerative cane prices fixed by the Government has been the major factors responsible for this development. The area under groundnut has been moving in the order of 1.38 per cent, however, the area under cotton was declining by 0.19 per cent. Changes in the cropping pattern in tank irrigation has taken place by substitution of groundnut for cotton and making the groundnut as the major commercial crop in the tank command area.

c) Analysis of well irrigated area in Tamil Nadu

Wells at present account for about 45 per cent of net irrigated area in Tamil Nadu. The growth in ground water development in the last three decades has been phenomenal and has come to be referred as pumpset revolution. The number of wells has increased from 9 lakhs in 1960-61 to as high as 18 lakhs in 1989-90. The area irrigated by wells has increased from about 6 lakh hectares to about 12 lakh hectares during this period. The extent of gross well irrigated area has been increasing from 1960-1990. The growth rate per year over this period was estimated at 1.05 per cent. This changes could also be compared with increasing net irrigated area by wells at 2.50 per cent per annum. Well irrigation plays a dominant role in the state agriculture for a variety of reasons such as (i) decreasing scope for and increasing cost of surface irrigation development, (ii) increasing demand for more controllable water supply, created by HYV technology and (iii) low private investment in contrast to huge public outlay on surface irrigation. An important difference between surface irrigation and wells is that the former is a public source in terms of ownership and maintenance while the latter is largely privately owned. Wells in Tamil Nadu irrigate on an average one hectare per well. Wells are dispersed fairly widely throughout Tamil Nadu, except Nilgiris and Kanyakumari districts. Nine well intensive districts viz., Coimbatore, Periyar, South Arcot, North Arcot, Madurai, Salem, Dharmapuri, Chengleput and Trichy account for about 76 per cent of total number of wells and for 80 per cent of net irrigated area under wells. In Northern and Southern districts, wells used to supplement tank irrigation, particularly at the later part of the crop season. Ground water had already been over exploited where the drawal in many parts of the state being continually more than recharge.

Factors affecting ground water recharge and extraction in Tamil Nadu has been analysed using the data on depth to water table, rainfall and number of wells, for the period from 1960 to 1990. Monthly water table fluctuations from 175 control wells and the annual mean water table were worked out. The following regression model is fitted using the Ordinary Least Squares method:

$$DW = 6.9254 - \underset{(4.7823)}{0.0216^{**}} RF + \underset{(3.9207)}{0.0843^{**}} WL$$

$$R^2 = 0.6942; \quad N = 30; \quad F = 31.2625^{**}$$

where, DW = depth to water table below ground level in metres

RF = mean of rainfall lagged 1 and 2 years, in mm. (e.g. for 1992, the mean of rainfall in 1990 and 1991 was taken)

WL = number of wells in the state in thousands lagged 1 year,

Figures in parentheses are t ratios
** indicates significant at one per cent level

The results indicated that the variables had expected signs and significant. An increase in the lagged mean rainfall by 10 mm could bring up the water table by 0.21 metre (i.e. decreases the depth to water table by 0.21 metre) and an increase by one thousand wells above the mean, could increase the depth to water table (i.e., pushes down the water table) by about 0.08 metre. The increases in depth to water table due to increase in number of wells has been an indirect effect caused by the sharing of aquifers that have limited supply of water among increasing number of wells.

Some of the immediate consequences of over extraction of ground water are

a) fall in water table forcing the farmers either to deepen the well or to abandon it depending upon the accessibility to financial resources;

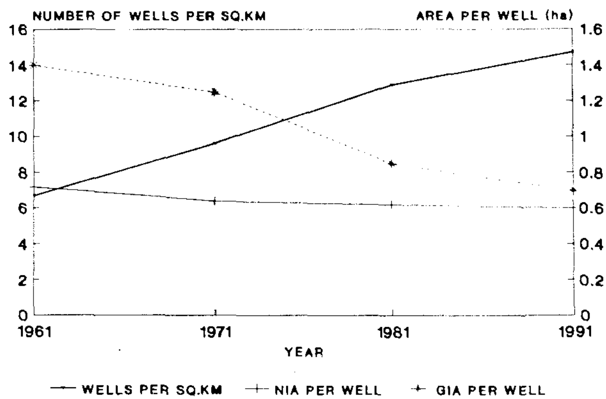
b) change in cropping pattern; and

c) reduced area under well irrigation.

Increasing number of wells (9 lakhs in 1960-61 to 18 lakhs in 1989-90) with decreasing water table has resulted in the stagnation of net irrigated area by the wells. Hence, the net area irrigated per well has decreased sharply over years from 0.8 hectare in 1960-61 to 0.6 hectare in 1989-90 (Figure 2). To identify the factors influencing area irrigated by wells, the following form of regression equation is estimated for well intensive as well as well non-intensive districts; and wells inside as well as wells outside the surface command area.

Well intensive districts where intensity of well irrigation is more than one are viz., Coimbatore, Periyar, South Arcot, North Arcot, Madurai, Salem, Chengleput, Trichy and Dharmapuri. Well non-intensive districts where intensity of well irrigation is one or less than one are viz., Tanjore, Kanyakumari, Tirunelveli, Pudukottai and Ramanathapuram.

FIGURE.2. IMPACT OF INTENSITY OF WELLS
ON AREA IRRIGATED



$$NW = a + b_1 RF + b_2 WD$$

NW = Net area irrigated per well in the districts in hectares

RF = Mean rainfall in mm lagged by 1 and 2 years,

WD = Density of wells defined as the ratio of total number of wells in the districts to the geographical area of the districts lagged by 1 year, and b_1 and b_2 are parameters to be estimated.

The results of the regression analysis are presented in Table 16. A comparison of the results for well intensive and well non-intensive districts had shown that the influence of both rainfall and density of wells on area irrigated per well were higher in well intensive districts than that of non-intensive districts. In well intensive districts every 1 cm increase in rainfall, could increase the net irrigated area per well by 0.0079 ha, while in non-intensive districts it was only 0.0052 ha. Similarly, the impact of density of wells on area irrigated per well was much higher in well intensive districts than that of non-intensive districts. While every additional well per square kilometre in intensive districts had caused a decrease in the net irrigated area per well by 0.08 ha, the corresponding reduction for non-intensive districts was only about 0.03 ha.

With respect to wells inside command area, every 1 cm increase in rainfall could increase net irrigated area per

Table 16. Regression analysis on factors influencing area irrigated by wells

Categories	Factors	Regression coefficient	t-value	R^2	N
Intensive districts	Constant	0.4189	1.237		
	Lagged mean rain (cm)	0.0079	4.236	0.6932	30
	Lagged well density (no./sq.km)	-0.0854	-7.592		
Non-intensive districts	Constant	0.3457	1.312		
	Lagged mean rain (cm)	0.0052	3.645	0.5741	30
	Lagged well density (no./sq.km)	-0.0317	-8.249		
Wells inside surface command	Constant	0.2946	0.816		
	Lagged mean rain (cm)	0.0064	5.317	0.7652	30
	Lagged well density (no./sq.km)	-0.0012	-4.705		
Wells outside surface command	Constant	0.2583	0.917		
	Lagged mean rain (cm)	0.0089	6.971	0.8143	30
	Lagged well density (no./sq.km)	-0.0937	-3.826		

well by 0.0064 ha. In the case of wells outside command area,every 1 cm increase in rainfall would increase the net irrigated area per well by 0.0089 ha, and it was higher than the wells inside command because wells outside the command area depend on rainfall for recharge. While every additional well per square kilometre inside the command had caused a decrease in the net irrigated area by 0.0012 ha, the corresponding reduction for wells outside the command was about 0.09 ha. In the case of wells inside command area, tanks and canals had contributed to raise the ground water table.

The negative coefficient for intensity of wells had indicated a clear case of externality caused by digging additional wells in both the districts, even though the externality was much higher in intensive districts. Private exploitation of underground water by numerous individual farmers had tended to result in an indiscriminate and unregulated proliferation of wells. Excessive exploitation of ground water had led to a permanent decline in the water table. More importantly the water yield from an existing well had tended to diminish as the water table recedes. In the face of rising cost of digging wells and reduced water availability, the farm output had been affected. Thus in an excessively exploited region, additional investment in new wells might prove counter-productive in the sense that additional area contributed by them might offset the existing area.

The other major reason for falling ground water table might be the increase in area under crops like sugarcane which consumes more water. Table 17 indicates the area under cultivation of major crops under well irrigation. The share of rice has decreased from about 56 per cent in 1960-61 to about 38 per cent in 1989-90 under wells. However, sugarcane and groundnut has witnessed a rapid growth in area under wells indicating commercial agriculture has been the important feature in this mode of irrigation. These two crops shared about 3 per cent each in 1960-61 and increased to about 10 per cent each in 1989-90. However, cotton area has been stagnating due to pest and diseases and higher price fluctuations.

Performance of the Irrigation Sources

Earlier discussions presented a general picture on development of irrigation sources over the period from 1960 to 1990. The next step is to examine the determinants of the levels of these sources. The determinants generally refer incentives, constraints, resources, environment and other endogenous variables. The conceptual framework calls for a simultaneous functional analysis as these sources are

Table 17. **Gross well irrigated area in Tamil Nadu**

(Hectares)

Year	Rice		Sugarcane		Groundnut		Cotton		All crops
	Area	Per cent	Area	Per cent	Area	Per cent	Area	Per cent	Area
1960-61	679197	56.37	37012	3.07	40305	3.34	47904	3.98	1204955
1961-62	747301	59.56	44058	3.51	55315	4.41	55063	4.39	1254609
1962-63	792332	59.29	31874	2.39	55202	4.13	68378	5.12	1336265
1963-64	762016	57.79	42587	3.23	61159	4.64	68184	5.17	1318609
1964-65	713007	60.61	39956	3.40	41631	3.54	48895	4.16	1176467
1965-66	658775	55.36	58810	4.94	54568	4.59	50147	4.21	1190030
1966-67	814410	61.41	52511	3.96	72732	5.48	55563	4.19	1326079
1967-68	751549	53.88	63113	4.52	96013	6.88	52716	3.78	1394853
1968-69	695893	46.78	71634	4.82	66244	4.45	52265	3.51	1487529
1969-70	760332	55.51	80742	5.89	67941	4.96	49229	3.59	1369772
1970-71	737084	47.33	67089	4.31	95791	6.15	51940	3.34	1557375
1971-72	728219	52.50	56886	4.10	104998	7.57	74354	5.36	1387098
1972-73	770177	57.36	67457	5.02	76475	5.70	58333	4.34	1342779
1973-74	727337	45.97	87499	5.53	115376	7.29	59170	3.74	1582164
1974-75	581566	46.99	93408	7.55	81295	6.57	57345	4.63	1237692
1975-76	709172	55.75	59054	4.64	66060	5.19	35465	2.79	1272077
1976-77	578918	47.36	89813	7.35	68320	5.59	51287	4.20	1222288
1977-78	755346	54.75	78465	5.69	85024	6.16	79819	5.79	1379549
1978-79	792249	50.85	103828	6.66	116480	7.48	89529	5.75	1558120
1979-80	797849	50.70	85131	5.41	142850	9.08	84236	5.35	1573525
1980-81	689543	48.51	106880	7.52	136813	9.63	64898	4.57	1421427
1981-82	701013	50.21	121935	8.73	119879	8.59	58637	4.20	1396279
1982-83	595828	49.59	110838	9.23	101755	8.47	44662	3.72	1201464
1983-84	654571	53.32	72182	5.88	97346	7.93	41641	3.39	1227646
1984-85	683388	48.67	83016	5.91	149766	10.67	78926	5.62	1404058
1985-86	670432	47.83	112630	8.03	139104	9.92	77404	5.52	1401796
1986-87	596385	45.28	117818	8.94	127142	9.65	45858	3.48	1317212
1987-88	588847	42.52	170198	12.29	116701	8.43	66276	4.79	1384806
1988-89	572465	43.78	130200	9.96	132201	10.11	66123	5.06	1307605
1989-90	486542	38.27	129710	10.20	129938	10.22	65456	5.15	1271420

Source: Government of Tamil Nadu, Season and Crop Reports, Various years, Directorate of Agriculture, Madras.

interrelated and determined simultaneously in a given year. In doing so, it was important to keep in mind that changes in canal and tank irrigation reflect decisions made by government and thus was exogenous to individual farmer. On the other hand, expansion in area irrigated by wells largely reflects decisions made by farmers themselves. Although the decisions to expand the sources are made by both private and public sectors, some of the factors affecting these decisions are similar. The similarities stem from the fact that expansion decisions require scarce resources and therefore, the diversion of resources from one to another source requires that their value productivity in agriculture was greater in one source than in other sources. For these reasons, the present study will examine simultaneously the importance of incentives, constraints, resources, environment and other endogenous variables in determining levels of irrigation sources. The inter-relationship between variables are illustrated in Figure 3. Net irrigated area by source is used as a measure of irrigation capacity available in the short run. Evenson (1983)[2] and Schwarty (1986)[3] used gross irrigated area as the relevant

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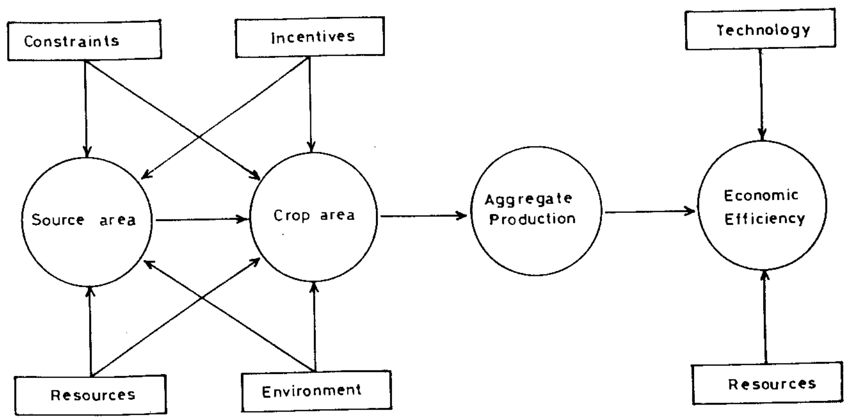
[2]R.E.Evenson, The Economics of Agriculture Growth: The Case of Northern India, Paper presented at the Economics Seminar Series, Colorado State University, USA, 1983.

[3]A.Schwarty, The Effect of High Yielding Varieties on Agricultural Labour Demand in Rural North India, Agriculture Workshop Paper, University of Chicago, USA,1986.

FIGURE 3. INTER RELATIONSHIP BETWEEN VARIABLES IN THE SIMULTANEOUS EQUATION MODEL



irrigation variable as they assumed the intensity with which the land irrigated by a source was exogenous. McGuirk and Mundlak (1991)[4] used net irrigated area as the relevant irrigation variable as they assumed the intensity with which the land irrigated by a source was endogenous. The present study also assumed that the intensity with which the land was irrigated by a source was endogenous and therefore this study measures the relevant source of irrigation by net irrigated area.

The most drastic change in irrigation took place in net area irrigated by wells which was doubled between 1960 and 1990. Over the same period, net area irrigated by canals increased marginally and net area irrigated by tanks decreased. Although both the private and public sectors seem to have responded to the favourable economic conditions of the period, particularly larger increase in well irrigation was an indication of the intensity where farmers responded.

As explained in Chapter III, analytical framework for the simultaneous analysis of changes in the net irrigated

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[4] A.McGuirk and Y.Mundlak, *Incentives and Constraints in the Transformation of Punjab Agriculture*, Final Report, International Food Policy Research Institute, Washington, 1991.

area under the sources viz., canal, system tank, non-system tank and well inside surface and well outside surface command over the period from 1960-1990 has two blocks of equations. The first block consisted of sets of five equations describing the allocation of area to the different water sources. As described earlier, the allocation decisions are determined by five sets of variables viz., incentives, constraints, resources, environment and lagged endogenous variables. The second block consisted of five sets of equations. Each set consisted of four sub-sets of crop area allocation equations in the respective water source. Gross irrigated area by crops in different sources was used as dependent variable which depended on incentives, constraints, resources, environment and lagged endogenous variables. The crops selected for the area allocation under each source were rice, sugarcane, groundnut and cotton as these crops accounted for about 85 per cent of the irrigated area in the State. The above two blocks of equations determined simultaneously as a system using the iterative Zellner[5] efficient method. The system has been estimated through LIMDEP package.[6] Among the linear and log linear

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[5]A. Zellner, "Estimates for Seemingly Unrelated Regression Equations: Some Exact Finite Sample Results", **Journal of the American Statistical Association**, 58(3): 977-992, 1963.

[6]W. H. Green, Limdep Manual, Department of Economics, Graduate School of Business Administration, New York University, New York, 1985.

forms attempted, log linear model has explained well and hence further discussions were confined to log linear model only. The first block explained the important determinants of different irrigation sources and the variables included in the first block are presented and summarised below:

$$NSA_i = a_0 + a_1 \text{ (Incentives)} + a_2 \text{ (Constraints)} + a_3 \text{ (Resources)} + a_4 \text{ (Environment)} + a_5 \text{ (Other variables)} + U_1$$

(i = 1 to 5 denote sources)

First Block - Definitions of Source Equations

Dependent Variables

1. Net irrigated area by canal(hectares)
2. Net irrigated area by system tank (hectares)
3. Net irrigated area by non-system tank (hectares)
4. Net irrigated area by 'wells inside command' (hectares)
5. Net irrigated area by 'wells outside command' (hectares)

Independent Variables

Constraints

1. Total net area irrigated for all the sources (hectares)
2. Population (numbers)
3. Number of wells

Incentives

4. Real Agricultural GDP lagged one year per capita (rupees)
5. Agricultural production index

Resources

6. Fertilizer availability (NPK-Kgs per hectare)

7. Infrastructural index

Environment

8. Mean rainfall of North east and South west monsoon (mm)

9. Mean rainfall of current and lag one year (mm)

10. Mean rainfall of lag one and lag two years (mm)

Other Variables

11. Net area irrigated by canals lag one year (hectares)

12. Net area irrigated by system tanks lag one year (hectares)

13. Net area irrigated by non-system tanks lag one year (hectares)

14. Net area irrigated by wells inside command lag one year (hectares)

15. Net area irrigated by wells outside command lag one year (hectares)

Explanations for some of the variables in the First Block are given below:

Constraints

The capital available for irrigation development is limited and it is the major constraint for further expansion of the irrigation sources. Since direct measure of amount spent for irrigation investment yearwise was not available, an alternative, total net irrigated area was used as the final output of any irrigation investment and it was the area actually irrigated. This variable would also measure the marginal share of each source if there was an increase in the total net irrigated area.

Population pressure is also an important constraint adversely affecting the performance of the existing irrigation systems. Population as independent variable would capture the effect of foreshore encroachment, housing settlement, unauthorised cultivation, micro land use and overgrazing in the catchment areas. This variable also would capture the effect of physical factors such as deforestation and siltation over years.

Number of wells has been included as explanatory variable mainly to capture the effect of increasing well intensity on net irrigated area.

Incentives

The per capita agricultural GDP lagged one year measured in constant prices has been included as an incentive which could include the effect of private investment on irrigation. This variable also could represent the use of comprehensive physical and human capital used in the development of irrigation. Lagged per capita agricultural GDP was taken to allow for time element which was involved in the irrigation investment.

The changes in the productivity and profitability of irrigated agriculture brought about by technical change are captured by the variable, agricultural production index. The variable expressed as a composite index, with the average value of productivity of all crops, with 1960-61 as base, could act as the proxy variable for agricultural technology.

Resources

Inputs and infrastructure facilities are the major measures of resources availability. Lagged total fertilizer per hectare has been included as an indicator of fertilizer availability. Lagged resources has been included to allow time element involved in the expansion of irrigated area.

Allocation of private funds to water resources development would have also influenced by factors like roads, railways, communications, electricity and commercial banks. Infrastructural index was calculated and included in the model.

Environment

Environmental factors that affect the area allocation of sources are difficult to quantify. One environmental variable that is easy to quantify and on which data are variable is rainfall. Thus, specific rainfall variables are incorporated to capture the effect of environment on the area allocation decisions.

Other Variables

As the equation indicates, the level of irrigation investment also depends on the existing capital stock. The available stock has been represented by the sourcewise lagged dependent variable. Lagged net irrigated area by source has been included separately in their respective models because such a decomposition would allow the various components of lagged net irrigated area to have different effects on the irrigated sources.

The results of the analysis of the simultaneous equation system could give a broad conclusion about the factors affecting the performance of irrigation sources viz., canal, tank (system and non-system tank), well (inside and outside command) (Table 18). In the canal equation, total net irrigated area, fertilizer availability and mean of current rainfall and rainfall lagged one year were the significant variables. As expected, these variables have positive sign. The result revealed that as total net irrigated area increases by 10 per cent, the net area irrigated by canals would increase by 2.99 per cent per year. Since total net irrigated area has been included in the model as a proxy variable for irrigation investment, its impact has been felt more on canals as could be seen from the table. This was due to larger share of irrigation

Table 18. Estimates of source equations

Explanatory variable	Dependent variable : Net irrigated area of				
	Canal	System tank	Non-system tank	Well inside command	Well outside command
Constraints					
Total net irrigated area	0.2987** (4.2359)	0.0635** (2.8973)	0.2079** (3.2519)	0.2194** (4.1587)	0.1845** (3.5642)
Population	-0.0018 (-1.5469)	-0.0139** (-2.9416)	-0.0264** (-3.3462)	+0.0004 (+1.1684)	-0.0035 (-1.4213)
Number of wells	+0.0009 (+1.9572)	-0.0036 (-2.4621)	-0.0006 (-1.8436)	+0.0013 (+1.9763)	-0.0247** (-3.6231)
Incentives					
Real AGDP per capita lag one year	-0.0007 (-1.8456)	+0.0014 (+2.1659)	-0.0025 (-2.3462)	0.0169** (3.2645)	0.0023 (2.5274)
Production index	0.0039 (1.8326)	0.0027 (1.4375)	-0.0016 (-1.2497)	0.0279** (2.9653)	0.0052 (2.2463)
Resources					
Fertilizer availability	0.0248** (3.2954)	0.0084 (2.1942)	0.0097 (1.4538)	0.0375** (4.8621)	0.0069 (0.9745)
Infrastructural index	0.0017 (2.3456)	0.0045 (2.6153)	0.0009 (1.7456)	0.0148** (3.1672)	0.0039 (2.2641)
Environment					
Mean rainfall of NE and SW monsoon	0.0078 (1.7654)	0.0592** (3.3215)	0.0834** (5.4213)	0.0095 (1.9457)	0.0063 (1.7415)
Mean rainfall of current and lag one year	0.0472** (3.5456)	0.0065 (1.6251)	0.0071 (1.5981)	0.0062 (2.3564)	0.0348** (3.8215)
Mean rainfall of lag one and lag two years	0.0091 (1.1256)	0.0004 (0.9328)	0.0072 (1.4962)	0.0013 (1.1892)	0.0652** (5.7316)

Table 18 (Contd.)

Explanatory variable	Dependent variable : Net irrigated area of				
	Canal	System tank	Non-system tank	Well inside command	Well outside command
<u>Others</u>					
Canal area lag one year	0.0049 (1.9641)	-	-	-	-
System tank area lag one year	-	0.0036 (1.4356)	-	-	-
Non-system tank area lag one year	-	-	0.0027 (1.7865)	-	-
Well inside command area lag one year	-	-	-	0.0053 (1.9215)	-
Well outside command area lag one year	-	-	-	-	0.0062 (1.8305)
Intercept	13.9341	10.8503	9.3257	8.4235	7.9086
R-Square	0.5826	0.4356	0.3952	0.6293	0.5734
Number of years	30	30	30	30	30

Figures in parentheses are t statistics
** Significant at one per cent level

investment allotted to the development of canal irrigation as compared to other sources. For example, during the period from 1960 to 1990, the major and medium irrigation projects shared about two-third of total irrigation investment in Tamil Nadu.[7]

The results also showed the importance of input supply particularly fertilizers in the expansion of canal irrigated area. Holding all other variables constant, if fertilizer availability increases by 10 per cent, the net area irrigated by canal would increase by 0.25 per cent per year. This positive and significant relationship between fertilizer and canal source confirmed the fact that both are complementary. Current rainfall and rainfall lagged one year has also influenced the canal irrigated area positively and significantly. Since the catchment area of canal systems lie in the western ghats, the effect of time lag of rainfall on canal command area was reflected by the current and rainfall lag one year. Keeping all other variables constant, if current rainfall and rainfall lag one year increases by 10 per cent, the net irrigated area by canal would expand by 0.47 per cent.

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[7]Government of Tamil Nadu, Tamil Nadu: An Economic Appraisal, Various years, Department of Statistics, Madras.

The simultaneous regression equation for net irrigated area under system tanks had total net irrigated area, population and mean of North east monsoon rainfall and South west monsoon rainfall as significant variables. Holding all other variables constant, if total net irrigated area increases by 10 per cent, the net irrigated area under system tanks would increase by 0.64 per cent. As expected total net irrigated area had the positive and significant relationship since it was the proxy for irrigation investment. In terms of a **priori** expectations, population had a negative but significant effect on net irrigated area by tanks. In Tamil Nadu for every 10 per cent increase in population, the irrigated area under study would decrease by 0.14 per cent. As expected, the encroachment, housing settlement and unauthorised cultivation had contributed to the negative coefficient of the population variable. Of the rainfall variables, the mean rainfall of North east and South west monsoon had positive influence on irrigated area under system tanks. The net irrigated area would increase by 0.59 per cent if rainfall increases by 10 per cent. North-east and South-west monsoon rainfall had explained the net area equation as this variable would assess the impact of both seasons on filling the tanks.

In the case of non-system tanks, three variables viz., total net irrigated area, population and mean rainfall of North-east and South-west monsoon were significant. The analysis also had shown that the impact of population on irrigated area was greater in non-system tanks than in system tanks. The non-system tanks have not been properly maintained by PWD and local communities over years compared to system tanks. Deforestation, lack of soil conservation measures in the catchment and siltation over years had reduced the storage capacity of non-system tanks. As expected, the average of monsoon rain had higher effect on non-system tanks than system tanks. Non-system tanks have own catchment areas and are not linked to canals or rivers as in system tanks and hence they have to depend on monsoon rainfall for filling the tanks.

In the equation for wells inside command area, total net irrigated area, real agricultural GDP per capita lag one year, production index, fertilizer availability and infrastructural index had positive and significant influence on the expansion of area under wells inside command area. Holding all other variables constant, if total net irrigated area increases by 10 per cent, the net area under wells inside command area would be estimated to increase by 2.19 per cent. It shows the impact of irrigation investment on the expansion of wells inside the command area. This expansion was greater than that of wells outside command area due to the better recharge of wells inside command, conjunctive use of well water with surface irrigation, interaction and complementary effect of well water with other inputs such as fertilizer. If real agricultural GDP per capita lag one year increases by 10 per cent, well area inside command would increase by only 0.17 per cent. This variable has not been significantly contributing to expansion of area under surface irrigations which have been met mainly by government sources and not by private investment. The change in area irrigated by wells inside the command was directly responsive to incentives viz., agricultural GDP per capita lag one year and production index. Particularly larger elasticity under private sources has been due to incentives which indicated the intensity with which farmers have responded to the favourable economic conditions of the period. Similarly, the effect of fertilizer availability and infrastructural index could be interpreted. The impact of fertilizer availability have been higher in wells inside command area than other sources, as these farms has better control over water supply, the input availability has induced the acreage under well inside command area due to interaction effect.

The equation for wells outside command area had four significant variables viz., total net irrigated area, number of wells, mean rainfall of current and lag one year and mean rainfall of lag one year and lag two years. If total net irrigated area increases by 10 per cent, the area under wells inside the command area would increase by 1.85 per cent. This variable was a proxy for irrigation investment and it showed the impact of investment on the expansion of wells outside the command area. The significant and negative coefficient for number of wells had indicated that if number of wells increases by 10 per cent, the area under wells outside command area would decrease by 0.25 per cent per year and this might be due to the scarcity of water under this source. The result could indicate that the digging additional wells would just share the existing command area and thus resulting in exploitation of ground water. The environmental variable, viz., rainfall of lag one and two years had positive and significant influence due to the fact that the recharge of well water was mostly influenced by past years' rainfall and time element involved in recharge of ground water.

Having discussed the performance of irrigation sources from 1960-1990 in the first stage, a detailed analysis of area allocation of crops within a particular source was attempted in the second stage. The variables included in the second stage (area allocation under crops) are presented and summarized as follows:

$$A/S_{ij} = \beta_0 + \beta_1 \text{ (Incentives)} + \beta_2 \text{ (Constraints)} + \beta_3 \text{ (Resources)} + \beta_4 \text{ (Environment)} + \beta_5 \text{ (Other variables)} + U_{11}$$

(i = 1 to 5 denote sources; j = 1 to 4 denote crops)

Definition of variables included in the second block to explain crop area allocation in different sources viz., canal, system tank, non-system tank, well inside command and well outside command area are summarized.

Sourcewise Area Allocation Among Crops

Dependent Variables

1. Gross rice area irrigated by source (hectares)
2. Gross sugarcane area irrigated by source (hectares)
3. Gross groundnut area irrigated by source (hectares)
4. Gross cotton area irrigated by source (hectares)

Independent Variables

Constraints

1. Gross area irrigated by source (hectares)

Incentives

2. Expected price of rice per ton
3. Expected price of cane per ton

4. Expected price of groundnut pods per ton
5. Expected price of lint per quintal

Resources

6. Fertilizer availability (NPK-Kgs per hectare)
7. Pesticide availability (Kgs per hectare)
8. Infrastructural index

Environment

9. Current rainfall (mm)

Other Variables

10. Gross rice area lag one year (hectares)
11. Gross sugarcane area lag one year (hectares)
12. Gross groundnut area lag one year (hectares)
13. Gross cotton area lag one year (hectares)

The specific variables that could capture the effect of incentives, constraints and environment on the area allocation decisions are described below:

Incentives

The incentive measures included are product and factor prices. Under uncertainty, prices are replaced by expected prices. Thus, the variables included to capture the relevant incentives for producers are product prices deflated by wage, all lagged one year. The price variables are deflated by wage to ensure that the area share equations are homogenous of degree zero in all prices.

Constraints

The term constraint has been used to represent the available irrigation facilities that affected the implementation of technology. Since decisions on area allocation has been made conditional on the available land and irrigation facilities, gross irrigated area by source has been used as a measure of the irrigation capacity available in the short run. The gross area irrigated by sources has been included in the area equations to incorporate the effect of irrigation intensity on area allocation of rice and groundnut.

The expected supply of fertilizers has been measured by the supply available during last year (measured in terms of total nutrient (NPK) content per hectare). Obviously, lagged supply values were independent of contemporaneous shocks in demand. No attempt was made to construct a more elaborate specification of expectations of fertilizer availability, as a strong response to increase in supply of fertilizers was captured well by the present procedure. Similarly, the expected supply of pesticide was measured by the supply available last year (kgs per hectare) and incorporated in the model.

Infrastructure

The availability of physical infrastructure, represented here by the availability of roads, railways, telecommunications, electricity and commercial banks have a potential influence on the area allocation decisions. Specifically, the availability of roads affected the degree to which the rural areas were integrated within the market. The infrastructural index has been developed as per the procedure outlined.

Environment

Variable current rainfall has been included to capture the importance of preplanting rain on the crop area allocation decisions.

Canal area allocation among different crops viz., rice, sugarcane, groundnut and cotton were estimated simultaneously. The estimated elasticities of canal area allocation under different crops are presented in Table 19. The results suggest that the constraint viz., gross canal irrigated area was the important variable in determining area allocation among crops. This constraint had a positive and significant influence on area allocation of selected crops viz., rice, sugarcane, groundnut and cotton. Holding all other variables constant, if gross canal irrigated area increases by one per cent, the gross irrigated area would raise by 0.76, 0.13, 0.04 and 0.03 per cent under rice,

Table 19. Estimation of canal area allocation

Explanatory variable	Dependent variable: Gross canal irrigated area allotted to			
	Rice	Sugarcane	Groundnut	Cotton
Constraints				
Gross canal irrigated area	0.7635** (6.4195)	0.1298** (3.5721)	0.0424** (3.0132)	0.0286** (3.1562)
Incentives-Expected Price				
Rice	0.0087 (2.1064)	-0.0029 (-0.9763)	0.0018 (1.6507)	0.0057 (1.4239)
Sugarcane	-0.0016 (-0.8932)	0.0341** (3.5482)	-0.0054 (-1.6203)	-0.0048 (-0.9412)
Groundnut	0.0028 (1.0987)	0.0076 (1.6279)	0.0049 (1.8603)	-0.0062 (-1.4736)
Cotton	0.0019 (0.8376)	-0.0043 (-0.7416)	-0.0087 (-1.9182)	0.0079 (2.0438)
Resources				
Fertilizer availability	0.0157** (2.8946)	0.0034 (1.7592)	0.0046 (1.7235)	0.0032 (1.4805)
Pesticide availability	0.0059 (2.5681)	-0.0017 (-0.4251)	0.0015 (0.6397)	0.0327** (3.4805)
Infrastructural index	-0.0013 (-0.7901)	0.0152** (2.9176)	0.0024 (1.3579)	0.0054 (2.0817)
Environment				
Rainfall	-0.0016 (-1.4953)	-0.0018 (-1.5706)	0.0023 (2.2479)	0.0021 (1.9235)
Others				
Rice area lag one year	0.0019 (0.8428)	-	-	-
Sugarcane area lag one year	-	0.0078 (2.1482)	-	-
Groundnut area lag one year	-	-	0.0086 (1.9841)	-
Cotton area lag one year	-	-	-	0.0008 (0.6497)
Intercept	10.9612	10.4593	7.2659	8.0975
R-Square	0.4967	0.5345	0.4326	0.3802
Number of years	30	30	30	30

Figures in parentheses are t statistics
** Significant at one per cent level

sugarcane, groundnut and cotton respectively. These percentages could also be interpreted as marginal shares under each crop. This finding could suggest that an increase in canal irrigated area, had a higher and favourable effect on rice than in other crops due to the suitability of canal water and delta region for rice cultivation rather than for other crops. In rice, cotton and groundnut equations, only gross canal irrigated area were significant. In sugarcane equation, the other positive and significant variables were its own price and infrastructural index. An increase in price of cane by 10 per cent would increase area under this crop by 0.34 per cent. Hence remunerative prices given to sugarcane (Rs.150 per tonne in 1971 to Rs.525 per tonne in 1992) might also be attributed to the three fold increase in area from 1960-61 (11,000 hectares) to 1989-90 (31,000 hectares). Holding other variables constant, an increase in infrastructural facilities by 10 per cent would increase sugarcane area by 0.15 per cent. This finding could reveal that the availability of infrastructure encouraged the area under sugarcane. It had also indicated the roads are needed for transportation of canes to the factories.

Area allocation under system tank among different crops viz., rice, sugarcane, groundnut and cotton were estimated simultaneously. The estimated results are presented in Table 20. The result could suggest that the

Table 20. Estimation of system tank area allocation

Explanatory variable	Dependent variable: Gross system tank irrigated area allotted to			
	Rice	Sugarcane	Groundnut	Cotton
Constraints				
Gross system tank irrigated area	0.6483** (4.8256)	0.1508** (3.2397)	0.0623** (3.0975)	0.0492** (2.8579)
Incentives-Expected Price				
Rice	0.0072 (1.9843)	-0.0021 (-0.8432)	0.0023 (0.8941)	-0.0024 (-1.0352)
Sugarcane	-0.0083 (-1.5267)	0.0195** (3.2586)	-0.0070 (-1.4732)	-0.0096 (-0.8573)
Groundnut	-0.0035 (-0.9624)	-0.0028 (-0.9734)	0.0285** (3.4376)	-0.0042 (-0.7093)
Cotton	-0.0028 (-0.8952)	-0.0037 (-0.9842)	-0.0013 (-1.0724)	0.0026 (1.9845)
Resources				
Fertilizer availability	0.0019 (1.2508)	0.0046 (0.7853)	0.0017 (0.6245)	0.0025 (0.9634)
Pesticide availability	0.0042 (2.1534)	-0.0026 (-1.7509)	0.0024 (1.3256)	0.0051 (1.9823)
Infrastructural index	0.0012 (0.9405)	0.0079 (1.6804)	0.0037 (0.5142)	0.0019 (0.6237)
Environment				
Rainfall	0.0034 (1.2463)	0.0082 (1.5673)	0.0097 (1.4386)	0.0025 (1.3419)
Others				
Rice area lag one year	0.0048 (2.1537)	-	-	-
Sugarcane area lag one year	-	0.0027 (2.3016)	-	-
Groundnut area lag one year	-	-	0.0033 (2.2695)	-
Cotton area lag one year	-	-	-	0.0009 (1.8352)
Intercept	10.4382	8.7482	9.4751	8.2689
R-Square	0.4382	0.6482	0.5751	0.4089
Number of years	30	30	30	30

Figures in parentheses are t statistics
** Significant at one per cent level

constraint viz., gross irrigated area had a positive and significant influence on area allocation of rice, sugarcane, groundnut and cotton. The marginal share of rice was estimated at 0.65 and it was higher than the marginal shares of other crops. It might be due to the fact that system tanks provide continuous flow of water with low mineral content which permitted uninterrupted rice cultivation year after year. System tanks have also provisions to control over supply of water and hence there might be no drainage and salinity problems. In sugarcane equation, price had induced acreage under this crop and so the area under sugarcane had increased from about 3 per cent (32,000 hectares) in 1960-61 and to about 6 per cent (62,000 hectares) in 1989-90. Thus, the analysis revealed that gross system tank irrigated area was the important constraint which determined area allocation decision in system tanks.

The results for non-system tanks are presented in Table 21. The result could suggest that constraint viz., gross area (non-system tanks) and environment variable viz., rainfall were the important variables in determining crop area under these non-system tanks. The marginal share of groundnut was estimated at 0.44 and it was higher than other crops. Holding other variables constant, an increase in gross irrigated area under non-system tank by one per cent would increase the shares of rice, sugarcane, groundnut and

Table 21. Estimation of non-system tank area allocation

Explanatory variable	Dependent variable: Gross non-system tank irrigated area allotted to			
	Rice	Sugarcane	Groundnut	Cotton
Constraints				
Gross non-system tank irrigated area	0.2403** (3.1574)	0.0256** (2.8734)	0.4397** (3.2486)	0.2158** (2.9501)
Incentives-Expected Price				
Rice	0.0017 (1.2306)	0.0009 (2.0658)	-0.0008 (-0.0967)	-0.0012 (-0.8453)
Sugarcane	-0.0024 (-0.9532)	0.0085 (2.5276)	-0.0014 (-0.8645)	-0.0015 (-0.7608)
Groundnut	0.0013 (0.9862)	0.0027 (1.3452)	0.0098 (2.4187)	0.0007 (0.0469)
Cotton	0.0022 (1.8945)	-0.0019 (-0.7603)	-0.0006 (-0.0592)	0.0065 (2.0561)
Resources				
Fertilizer availability	0.0017 (1.6309)	0.0032 (2.1643)	0.0015 (1.4963)	0.0024 (1.8598)
Pesticide availability	0.0048 (2.1306)	0.0022 (0.8571)	0.0031 (1.9624)	0.0059 (2.4837)
Infrastructural index	0.0004 (0.7653)	0.0023 (1.8142)	0.0029 (1.8356)	0.0019 (1.7508)
Environment				
Rainfall	0.0038 (1.8647)	0.0095 (1.7683)	0.0247** (3.1656)	0.0356** (2.9807)
Others				
Rice area lag one year	0.0005 (0.6974)	-	-	-
Sugarcane area lag one year	-	0.0019 (1.3428)	-	-
Groundnut area lag one year	-	-	0.0045 (1.6209)	-
Cotton area lag one year	-	-	-	0.0053 (1.7642)
Intercept	10.8971	9.7482	10.5634	8.9507
R-Square	0.3259	0.3461	0.4962	0.4108
Number of years	30	30	30	30

Figures in parentheses are t statistics
** Significant at one per cent level

cotton by 0.24, 0.03, 0.44 and 0.21 per cent respectively. Since non-system tanks has always poor storages, there existed scarcity of water. Farmers has no control over supply of water. Hence they preferred the low risk crop like groundnut which demand comparatively lesser amount of water. Current rainfall variable was significant in groundnut and cotton equation. As expected, seasonal rainfall determined the storage capacity of tanks as these tanks were not linked to canals. The storage capacity in turn determined the acreage under groundnut and cotton. Farmers in this production environment has preferred groundnut and cotton even during monsoon seasons due to limited water supply in non-system tanks. Certain varieties of groundnut and cotton grown in this production environment were drought tolerant. The results for wells inside command had indicated that if gross well inside command area increases by one per cent, the marginal shares of rice, sugarcane, groundnut and cotton would be 0.37, 0.48, 0.07 and 0.02 per cent respectively (Table 22). The findings could reveal the suitability of sugarcane in this command area. As expected, this crop required larger amount of water (250 cm) than other crops and this requirement has been met by wells inside the command area by conjunctive use of surface and ground water. It is important to recognize the fact that a good deal of ground water that is being

Table 22. Estimation of well inside command area allocation

Explanatory variable	Dependent variable: Gross well inside command area allotted to			
	Rice	Sugarcane	Groundnut	Cotton
Constraints				
Gross well irrigated (inside command) area	0.3692**	0.4783**	0.0695**	0.0236**
	(3.8703)	(3.5271)	(2.9874)	(2.7501)
Incentives-Expected Price				
Rice	0.0089	0.0012	0.0023	0.0046
	(2.2143)	(1.8643)	(1.9705)	(2.1057)
Sugarcane	-0.0017	0.0382**	-0.0045	-0.0025
	(-1.2308)	(2.9741)	(-1.6309)	(-1.5432)
Groundnut	0.0029	0.0031	0.0089	0.0047
	(1.4875)	(1.5398)	(2.4507)	(2.2389)
Cotton	0.0018	-0.0038	0.0027	0.0045
	(1.2346)	(-2.0942)	(1.9835)	(1.6783)
Resources				
Fertilizer availability	0.0096	0.0065	0.0073	0.0084
	(2.4105)	(1.9305)	(0.9108)	(2.3675)
Pesticide availability	0.0061	-0.0019	0.0094	0.0309**
	(1.8243)	(-0.7562)	(2.1386)	(4.1527)
Infrastructural index	0.0043	0.0257**	0.0055	0.0091
	(1.7352)	(4.1369)	(1.9762)	(2.4283)
Environment				
Rainfall	-0.0012	0.0016	-0.0009	-0.0013
	(-0.9243)	(0.9875)	(-1.1324)	(-1.4095)
Others				
Rice area lag one year	0.0024	-	-	-
	(1.5961)			
Sugarcane area lag one year	-	0.0079	-	-
		(2.3485)		
Groundnut area lag one year	-	-	0.0057	-
			(1.6792)	
Cotton area lag one year	-	-	-	0.0032
				(1.5984)
Intercept	9.5372	10.4256	8.6534	9.4281
R-Square	0.6951	0.7145	0.6238	0.5307
Number of years	30	30	30	30

Figures in parentheses are t statistics
** Significant at one per cent level

lifted by wells inside command is infact surface water which has seeped into the ground.

In sugarcane equation, the other positive and significant variables were its own price and infrastructural index. Holding other variables constant, an increase in cane price by 10 per cent would increase area under this crop by 0.38 per cent. Remunerative prices given to sugarcane over this period might also be attributed to increase in sugarcane area under well irrigation from 37,000 hectares (3 per cent) in 1960-61 to 1,30,000 hectares (10 per cent) in 1989-90. An increase in infrastructural facilities by 10 per cent would increase sugarcane area by 0.26 per cent. Availability of infrastructure facilities encouraged area under sugarcane as roads are needed for transportation of canes to the factories. In cotton equation, the other significant variable was the pesticide availability. As larger amount of pesticide become available, the area allocated to cotton could increase which shows the importance of pesticides for cotton cultivation.

The results for wells outside surface command are presented in Table 23. The marginal shares of rice, sugarcane, groundnut and cotton are estimated at 0.24, 0.13, 0.26 and 0.28 per cent respectively. The findings could

Table 23. Estimation of well outside command area allocation

Explanatory variable	Dependent variable: Gross well outside command area allotted to			
	Rice	Sugarcane	Groundnut	Cotton
<u>Constraints</u>				
Gross well irrigated (outside command) area	0.2374** (2.9648)	0.1256** (2.7563)	0.2564** (3.0597)	0.2809** (3.8439)
<u>Incentives-Expected Price</u>				
Rice	0.0023 (1.5308)	-0.0027 (-1.4879)	-0.0013 (-0.9562)	-0.0008 (-0.7654)
Sugarcane	-0.0025 (-1.3692)	0.0086 (2.4309)	-0.0015 (-0.9642)	-0.0006 (-0.7497)
Groundnut	-0.0019 (-1.8752)	-0.0045 (-2.3096)	0.0469** (3.6271)	0.0064 (2.4105)
Cotton	-0.0021 (-1.3459)	-0.0037 (-1.9845)	0.0053 (2.1675)	0.0324** (3.1089)
<u>Resources</u>				
Fertilizer availability	0.0013 (1.4782)	0.0042 (2.1567)	0.0022 (1.8905)	0.0038 (2.0947)
Pesticide availability	0.0045 (1.9603)	0.0011 (1.2309)	0.0017 (1.4253)	0.0096 (2.1453)
Infrastructural index	0.0064 (2.1708)	0.0082 (2.3486)	0.0073 (2.2549)	0.0087 (2.5291)
<u>Environment</u>				
Rainfall	0.0025 (1.6432)	0.0036 (1.7245)	0.0041** (1.8369)	0.0049** (1.8975)
<u>Others</u>				
Rice area lag one year	0.0003 (0.5176)	-	-	-
Sugarcane area lag one year	-	0.0015 (0.8706)	-	-
Groundnut area lag one year	-	-	0.0026 (1.4397)	-
Cotton area lag one year	-	-	-	0.0018 (1.2354)
Intercept	10.9412	7.8391	9.5082	8.9073
R-Square	0.4318	0.3581	0.6295	0.5607
Number of years	30	30	30	30

Figures in parentheses are t statistics
** Significant at one per cent level

reveal the suitability of cotton in this command area. This might be due to lower water requirement of cotton compared to sugarcane and rice and this production environment has no saline and drainage problems which are ideal for cotton cultivation. Farmers preferred groundnut next only to cotton as this crop was also a low risky crop under water scarcity situations. Remunerative prices given to groundnut and cotton also encouraged area under these crops as it was evidenced from the sign and significance of the coefficients for own price elasticities of groundnut and cotton.

The Long-run Path

The sourcewise crop area allocation equations are used to obtain the long-run response of the system to changes in the irrigation variables. These responses would differ from the short run responses so for discussed. For instance, an expansion in the irrigation facilities could increase gross cropped area of the irrigated crops. Changes in irrigation facilities would also affect the fertilizer and pesticide allocation to the various sources. Thus, change in irrigation facilities could affect the acreage allocation of crops, yield and therefore output. These changes also could affect the differential profitability of irrigated agriculture. Sum of all these effects could be obtained by inducing a shock to, and by dynamically simulating the system. The full model was simulated by expanding net irrigated area under each source by 10 per cent with all other variables were endogenous. Only important variables such as constraints and resources were considered for the long-run analysis. By comparing the results derived from this exercise with results from the base run, it showed larger elasticities with respect to constraints and resources. These larger elasticities illustrated clearly that farmers responded positively and strongly to the economic variables in the long-run. The sourcewise long-run elasticities are presented in Tables 24-28.

Estimation of Productivity by Source

Source area allocation among crops had revealed the suitability of rice in canal and system tanks, groundnut in non-system tanks, sugarcane in well inside command and cotton in wells outside command. Following this, productivity analysis was done to estimate crop productivity by source and to measure allocative efficiency of irrigation sources in producing major irrigated crops. This analysis also would find out the type of crops to be suitable in a particular source. Because yields were available only by crop and not by source, the dependent variables in the productivity models were aggregate output by crop in the irrigated agriculture. The aggregate crop output was taken from statistical records published by the

Table 24. Long-run **elasticities for canal source**

Variable	Rice	Sugarcane	Groundnut	Cotton
Constraints				
Gross canal irrigated area	0.7648	0.1452	0.0475	0.0341
Resources				
Fertilizer availability	0.0283	0.0127	0.0091	0.0085
Pesticide availability	0.0076	0.0014	0.0063	0.0587
Infrastructural index	0.0017	0.0395	0.0053	0.0089

Note: Long-run elasticities are calculated by simulating the model with appropriate changes (for example, new canal area = net area under canal x 1.10). The model is re-run by expanding net irrigated area under each source by 10 per cent with all other variables are endogenous.

Table 25. Long-run elasticities for system tank source

Variable	Rice	Sugarcane	Groundnut	Cotton
Constraints				
Gross system tank irrigated area	0.6574	0.1692	0.0759	0.0517
Resources				
Fertilizer availability	0.0064	0.0091	0.0052	0.0076
Pesticide availability	0.0059	0.0023	0.0070	0.0107
Infrastructural index	0.0027	0.0145	0.0082	0.0056

Table 26. Long-run elasticities for non-system tank source

Variable	Rice	Sugarcane	Groundnut	Cotton
Constraints				
Gross non-system tank irrigated area	0.2514	0.0327	0.4405	0.2193
Resources				
Fertilizer availability	0.0046	0.0092	0.0081	0.0067
Pesticide availability	0.0084	0.0036	0.0049	0.0093
Infrastructural index	0.0032	0.0147	0.0035	0.0054

Table 27. Long-run elasticities for well inside command source

Variable	Rice	Sugarcane	Groundnut	Cotton
Constraints				
Gross well irrigated area inside command	0.3702	0.4895	0.0714	0.0285
Resources				
Fertilizer availability	0.0147	0.0095	0.0089	0.0124
Pesticide availability	0.0145	0.0027	0.0039	0.0628
Infrastructural index	0.0056	0.0482	0.0077	0.0093

Table 28. Long-run elasticities for well outside command source

Variable	Rice	Sugarcane	Groundnut	Cotton
Constraints				
Gross well irrigated area outside command	0.2409	0.1573	0.2706	0.2914
Resources				
Fertilizer availability	0.0142	0.0113	0.0074	0.0059
Pesticide availability	0.0047	0.0012	0.0039	0.0352
Infrastructural index	0.0068	0.0186	0.0079	0.0096

State Department of Agriculture. The aggregate output further depended on composition of sourcewise irrigated crops, which was endogenous within the system, but independent of the outcome of the current production, so the crop area predetermined by the source area allocation model. Hence, estimated sourcewise crop acreages were used as explanatory variables in the productivity model. The basic regression model is:

$$Y_i = r_0 + r_1 CA + r_2 ST + r_3 NT + r_4 WIS + r_5 WOS + e_t$$

Where, Y_i stands for aggregate crop output, for rice, sugarcane, groundnut and cotton. Each crop will have a separate production function. CA denotes area of crop under canal irrigation. ST refers to area of crop under system tank. NST denotes area of crop under non-system tank. WIS refers to area of crop under well inside command. WOS denotes area of crop under well outside command. r_0 refers to constant term and r_1 to r_5 are the marginal productivity of respective sources. The units of measurement of marginal products are as follows:

Rice in terms of paddy tonnes per hectare

Sugarcane in terms of cane tonnes per hectare

Groundnut in terms of pods tonnes per hectare

Cotton in terms of lint quintals per hectare

Equation estimated by OLS technique has explained well and this model measures the source productivity directly. This estimated production functions were then converted into a deterministic and probabilistic frontier function using linear programming techniques. This probabilistic function was further used to measure inter-source allocative efficiency for each crop. The estimated OLS function portrayed the average response and the frontier functions described maximum possible productivity of crops in each source. The OLS estimates are given in Table 29. In the case of rice, the marginal productivity was higher in system tank and it was estimated at 3.87 tonnes per hectare. In terms of canal marginal productivity of rice ranked second (next only to system tank) which was 3.52 tonnes per hectare. The result confirmed the fact that system tanks has improved water management practices for rice resulting in higher yield. In the case of sugarcane, the marginal productivity was higher in wells inside command and it was estimated at 126.73 tonnes per hectare. It might be worthwhile to interpret that sugarcane performance which was higher under wells inside command irrigation might be due to copius water supply at critical stages (protective role) and complementary effect (productive and interactive roles) of well water along with other inputs. Total water requirement of sugarcane was higher (250 cm) than other crops and it

Table 29. Estimation of productivity of crops by source

Crop	Analytical approach (sample size)	Dependent Variable : Aggregate Crop Output						R-Square
		Constant	Canal	System tank	Non-system tank	Well inside	Well outside	
Rice	OLS (30)	245.3681	3.5246	3.8752	2.9413	3.0785	2.5418	0.6952
		(1.7459)	(4.1397)	(5.2463)	(2.6805)	(2.8461)	(1.3769)	
	Deterministic (30)	253.5487	3.6152	3.9465	2.9508	3.2495	2.6351	
	Probabilistic (28)	254.6392	3.5748	3.9278	2.9647	3.2687	2.5783	
Sugarcane	OLS (30)	836.4207	108.2485	89.5632	76.8143	126.7259	83.5497	0.7234
		(0.8954)	(2.9374)	(2.5467)	(1.9657)	(3.5846)	(2.3681)	
	Deterministic (30)	845.2346	112.3596	91.7453	78.4206	134.6582	87.6346	
	Probabilistic (29)	843.6208	109.5684	92.8361	78.5134	135.4793	85.9452	
Groundnut	OLS (30)	964.5288	1.2397	1.5832	1.9547	1.3945	1.7356	0.6491
		(1.4273)	(0.8546)	(2.7614)	(4.2386)	(1.9836)	(3.4209)	
	Deterministic (30)	975.3124	1.2658	1.6245	1.9652	1.4369	1.7467	
	Probabilistic (28)	972.4358	1.2794	1.6379	1.9873	1.4205	1.7598	
Cotton	OLS (30)	457.6392	2.9453	3.4872	4.1642	3.0946	4.2579	0.5389
		(2.1034)	(1.8672)	(2.6391)	(2.9531)	(2.4257)	(3.8416)	
	Deterministic (30)	461.5487	2.9671	3.5806	4.2794	3.1789	4.3085	
	Probabilistic (29)	459.6302	2.9684	3.5274	4.2852	3.1502	4.3296	

Figures in parentheses below the OLS estimates are t statistics required water throughout the year. Hence in wells inside surface command suited well for sugarcane cultivation. The poor performance of other sources might be due to the scarcity of water particularly in a later stages of crop growth. In the case of groundnut the estimated marginal productivity was higher under non-system tanks (1.95 tonnes of pods per hectare). As groundnut required moderate water supply without salinity and water logging, non-system tanks and wells outside command suited well for groundnut cultivation compared to canal where it was not so good for groundnut cultivation due to drainage and water logging problems. The marginal productivity of groundnut was worked out to be 1.74 tonnes per hectare under wells outside surface command. In the case of cotton, the marginal productivity was higher under wells outside surface command with 4.26 quintals of lint per hectare. As this crop required moderate water supply (60 cm) without salinity and alkalinity, drainage and water logging, wells outside command suited well for cotton cultivation.

The productivity model so far described also confirmed the findings of source area allocation model among crops. The OLS function has been transformed into a deterministic frontier using linear programming techniques. The deterministic function reflected the maximum possible productivity of crops in each source. In all the crops' equations, the constant term in the deterministic function was greater than that estimated by the OLS method. In addition, many of the slope coefficients in the deterministic function has also improved. Thus, compared with the OLS model, the deterministic function shifted vertically along with shifts in the intercept and slope of the production function. Since the outliers in the deterministic approach affected the results, it could be converted into probabilistic frontier function. This approach ignored outliers (extreme observations) until the estimated coefficients were stabilised. Therefore the probabilistic model has been further used to estimate economic efficiency.

Measurement of Economic Efficiency

Once the area allocation is determined endogenously via system of simultaneous equation, it is important to study the efficiency with which these crops are produced. Technical, allocative and economic efficiencies were calculated using probabilistic functions (Table 30). The average technical efficiency had ranged from 0.73 in groundnut to 0.85 in rice. This had indicated that there existed a 15 and 27 per cent potential for increasing crop yield in rice and groundnut respectively at the existing level of their areas in different sources. The higher

Table 30. Sourcewise efficiency coefficients for selected crops

Type of efficiency	Rice	Sugarcane	Groundnut	Cotton
Technical	0.8469 (0.1236)	0.8107 (0.0974)	0.7296 (0.0695)	0.7634 (0.0942)
Allocative-overall	0.7034 (0.0513)	0.7142 (0.0784)	0.6985 (0.0892)	0.6592 (0.0784)
Allocative-canal	0.7543 (0.0817)	0.7396 (0.0961)	0.6405 (0.0823)	0.6219 (0.0935)
Allocative-system tank	0.7684 (0.0926)	0.7149 (0.0762)	0.7089 (0.0942)	0.6831 (0.0592)
Allocative-non-system tank	0.6935 (0.1245)	0.6836 (0.1157)	0.7852 (0.1298)	0.7163 (0.1085)
Allocative-well inside	0.7308 (0.0962)	0.7452 (0.0951)	0.6955 (0.0843)	0.6749 (0.1203)
Allocative-well outside	0.6826 (0.1149)	0.7265 (0.1392)	0.7284 (0.1358)	0.7598 (0.1247)
Economic	0.5957 (0.1386)	0.5790 (0.1269)	0.5096 (0.1478)	0.5032 (0.1649)
Number of years	30	30	30	30

Figures in parentheses are standard errors technical efficiency for rice (0.85) and sugarcane (0.81) were due to technological developments in these two crops viz., high yielding varieties, and application of modern inputs such as manures and fertilizers those which are complements with water. Overall allocative efficiency was the highest in sugarcane followed by rice, groundnut and cotton. Allocative efficiency in canal irrigation had contributed more for the overall allocative efficiency in rice. This result also confirmed the fact that rice would be more productive under canal irrigation. Allocative efficiency in the system tanks was also higher for rice than other crops. This fact might be attributed to the nature of production environment, water management technologies and copius water supply in the canals and system tanks meeting the water requirement for rice. Allocative efficiency in the wells inside command had been higher for sugarcane. This fact might be attributed to controlled water supply in this mode to meet the water requirement of sugarcane throughout the year for the crop. Allocative efficiency in the non-system tanks was higher for groundnut. As this source depended on monsoon rains for catchment, groundnut could be cultivated with higher economic returns in the non-system tanks than other sources. Allocative inefficiency in non-system tank was higher for sugarcane and rice. This might be due to rigidities implicit in the non-system tanks to supply adequate quantity of water needed at critical stages which would have contributed to efficiency in non-system tanks. Allocative efficiency in the wells outside surface command had revealed the suitability of cotton in wells outside command. This mode did not have the problems of salinity, water logging and drainage and so cotton would be ideally suitable in wells outside command. The allocative efficiencies are illustrated in figures 4 through 7.

Economic efficiency had ranged from 0.50 in cotton to 0.60 in rice. This means that there existed 50 per cent potential for increasing cotton yield in all sources of irrigation by removing technical and allocative inefficiencies. The allocative inefficiency of cotton was observed higher in canal and it needed proper attention in this mode. Possibly, canals have has the problems of water logging and poor drainage contributing to lower allocative efficiency of cotton in canal systems. Also rice had been the main crop under canals as the water allocation pattern in the first season (July-Oct, Nov) used to coincide with rainfall period.

Economic efficiency of groundnut had shown that productivity of groundnut could be increased by 49 per cent. Groundnut also needed proper attention in canals as this mode contributed more to allocative inefficiency. The poor

FIGURE.4. ALLOCATIVE EFFICIENCY FOR SUGARCANE

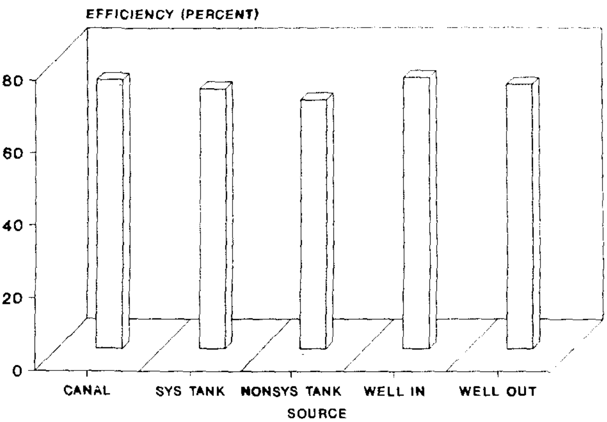


FIGURE.5. ALLOCATIVE EFFICIENCY FOR GROUNDNUT

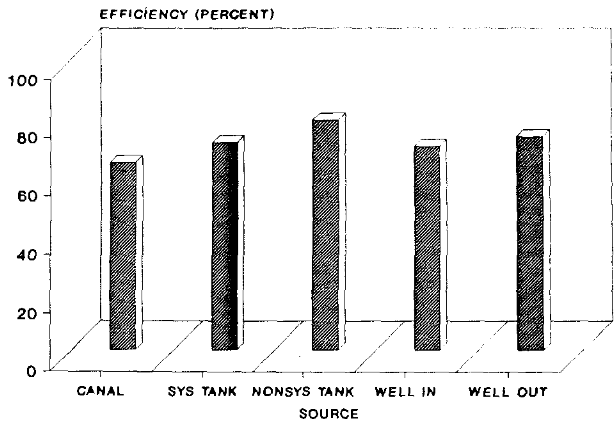


FIGURE.6. ALLOCATIVE EFFICIENCY FOR COTTON

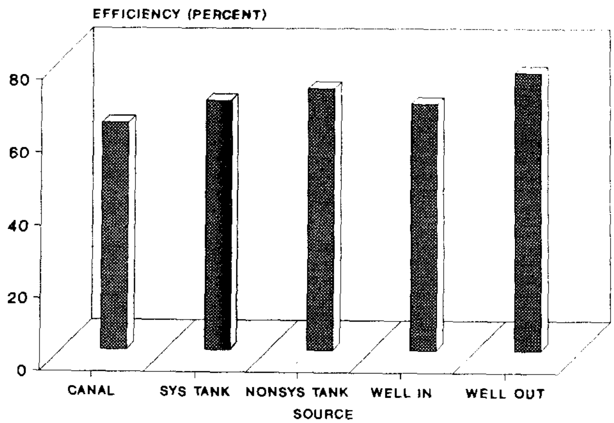
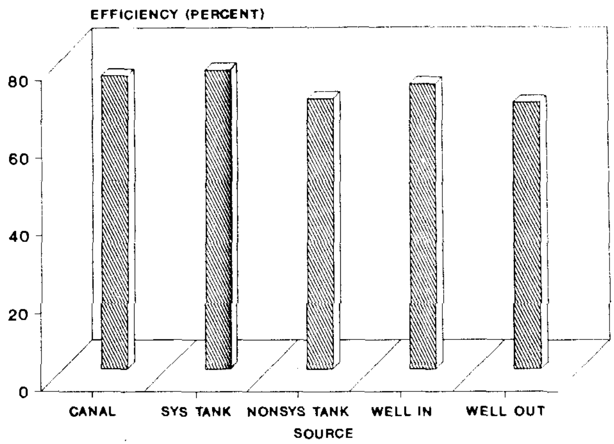


FIGURE.7. ALLOCATIVE EFFICIENCY FOR RICE



performance of groundnut in canals might be due to poor drainage, salinity, alkalinity and water logging in canal environment. Economic efficiency of sugarcane had revealed that productivity of sugarcane could be increased by 42 per cent. Sugarcane needed proper water management in non-system tanks to remove allocative inefficiencies since scarcity of water was higher in this mode particularly at later stages of the crop growth. There existed a 40 per cent potential for increasing rice output. Allocative inefficiency of rice was highest in wells outside as well as under non-system tanks. Rice would need proper water management in these sources as these modes face the problems of water scarcity. The economic efficiency measures had confirmed the results of area allocation model and productivity analysis about the suitability of rice in canals and system tanks, sugarcane in wells inside command, groundnut in non-system tanks and cotton in wells outside command (Table 31).

Determinants of Economic Efficiency

Once the economic efficiency is determined using frontier production function, it is important to study the determinants of efficiency with which these crops are produced. The results of economic efficiency measures could show that there existed high production gap in all crops between frontier and average production. This gap could be

Table 31. Suitability of crops in different sources

Crops	Best suited under sources based on		
	Area allocation	Productivity	Allocative efficiency
Rice	canal	system tank	system tank
Sugar cane	well inside	well inside	well inside
Groundnut	non-system tank	non-system tank	non-system tank
Cotton	well outside	well outside	well outside

explained by incorporating proper technology and resources used as explanatory variables. Sourcewise proportion of crop area irrigated had been included as technology variables to indicate the importance of the composition of techniques, chosen in the earlier planting decisions, in the determination of allocative and technical efficiency and thereby overall economic efficiency. Technical efficiency also had been influenced by the amount of fertilizer and pesticides used during the production period. Hence current fertilizer applied (NPK-kgs per hectare) and pesticide used in kgs per hectare were included as resources in the equation. As expected, given the high yielding modern varieties, fertilizer and pesticide application would shift the production function upward. The cropwise results of the OLS estimate are presented in Table 32.

It is important to emphasize that these results are consistent with the findings of area allocation models and productivity analysis. All equations has higher R-square values and fitted the data well. In rice equation, proportion of rice area irrigated in canal as technology variable had higher impact on economic efficiency. This might be due to the fact that productivity of rice has been relatively greater in canal and canal has been also allocatively efficient in rice cultivation. Given the high

Table 32. Determinants of economic efficiency

Explanatory variable	Dependent variable: Economic efficiency measure			
	Rice	Sugarcane	Groundnut	Cotton
TECHNOLOGY				
Proportion of crop area irrigated in canal	0.0687** (3.2591)	0.3275** (3.0641)	0.0243 (1.5967)	0.0357 (1.6275)
Proportion of crop area irrigated in system tanks	0.0295 (2.4082)	0.0689 (1.7564)	0.1261 (2.4314)	0.1952 (2.6528)
Proportion of crop area irrigated in non-system tanks	0.0096 (1.2476)	0.0047 (1.0742)	0.5786** (4.6219)	0.4672** (3.5294)
Proportion of crop area irrigated in wells inside command	0.0084 (1.3615)	0.4396** (3.7521)	0.1524 (2.6541)	0.1732 (2.5236)
Proportion of crop area irrigated in wells outside command	0.0069 (1.4257)	0.0974 (1.8164)	0.4162** (3.8239)	0.5391** (4.6519)
RESOURCES				
Fertilizer applied	0.0047** (2.8673)	0.0043 (2.1453)	0.0032 (2.1345)	0.0035 (1.9341)
Pesticide used	0.0035 (1.2736)	0.0009 (0.8530)	0.0042 (2.5342)	0.0652** (2.8345)
Intercept	0.0283	0.0691	0.0384	0.0185
R-Square	0.6897	0.7145	0.5917	0.5209
No. of years	30	30	30	30

Figures in parentheses are t statistics
** Significant at one per cent level

yielding varieties of rice and modern technology, fertilizer usage during the production process has shifted the production function of rice and increased the technical efficiency and thereby economic efficiency.

In the case of sugarcane equation, coefficient of the variables, proportion of area irrigated in canal and proportion of area irrigated in wells inside command were positive and significant. These technology variables indicated the importance of composition of sources chosen for sugarcane planting in the determination of overall output and economic efficiency of the crop. In the case of groundnut, proportion of crop area irrigated in non-system tank and proportion of area irrigated wells outside command were significant variables. As expected, the performance and productivity of groundnut were better in non-system tanks and wells outside the command and these sources were also allocatively efficient in groundnut cultivation. The economic efficiency of cotton had been influenced by proportion of area irrigated in non-system tanks and pesticide used. It might be recalled that an increase in the availability of pesticide significantly increased the area allotted to cotton. Given the higher yields of modern varieties of cotton, overall economic efficiency would increase as more inputs were applied. Wells outside command

and non-system could have conducive production environment for cotton cultivation and so these sources were allocatively and technically efficient for cotton production. To summarise, the results had shown that rice possibly suited well under canals and system tanks, sugarcane under wells inside command, groundnut under non-system tanks and cotton under wells outside surface command.

SUMMARY AND CONCLUSIONS

CHAPTER VI

SUMMARY AND CONCLUSION

The importance of water as a valuable resource for agriculture can never be over-emphasized. The increasing need for crop production for the growing population has necessitated rapid expansion of irrigation throughout the country. With the result, India has today the world's second largest irrigated area next to China. From 23.2 million hectares in 1951-52 which marked the beginning of planned development, the gross irrigated area in the country has gone upto 81 million hectares in 1989-90, registering about three fold increase during the past four decades.

Agricultural supply has responded to price policies complemented by other non-price measures such as irrigation, infrastructure, research and extension. There are certain problems and related issues in the water resources development. Though the well sources area move in the upward direction in the state, there has been a gradual decline in the area under tank irrigation and stagnation in the canal irrigated area. The problems are to identify and evaluate the factors associated with supply shift in different sources and to find out the suitability of crops to be grown in a particular source in terms of area allocation, productivity and efficiency in Tamil Nadu. If an individual source or a crop is considered separately for analysis, it would not give a satisfactory picture in terms of their long term trend in area, yield and supply. Hence all the sources and major crops grown in these sources are considered simultaneously for the present study.

The general objective is to study the economic variables influencing the performance of water sources and major irrigated crops in Tamil Nadu. The specific objectives are: 1. to identify and determine the factors influencing the expansion of irrigated sources; 2. to identify and analyse the economic variables explaining the allocation of irrigated land among crops viz., sugarcane, groundnut and cotton in each source and 3. to assess inter-source efficiency and determinants of efficiency in the production of these crops. The present study was undertaken in Tamil Nadu covering all sources of irrigation in Tamil Nadu. The findings are summariesed in this chapter.

Growth of Irrigation in Tamil Nadu

Irrigation is vital to Tamil Nadu economy as it helps to relieve agriculture from dry and rainfed conditions. The characteristics of rainfall distribution in Tamil Nadu discussed in the earlier chapter, have a vital bearing on the extent and reliability of irrigation. All sources of irrigation in the state viz., canals, tanks and wells depend on rainfall for their replenishment. In the late eighties, the ratio of gross irrigated area to gross sown area was 47 per cent in Tamil Nadu as compared to the all India average of 35 per cent. Though the growth in the extent of irrigation in terms of net irrigated area has been varying between periods, certain broad conclusions could be made. The area under canal irrigation has stagnated and tank irrigated area has declined, while there has been a striking increase in area under well irrigation. Wells now contribute to nearly 45 per cent of net irrigated area as compared to about 24 per cent in the 1950s. The net area irrigated by tank was about 37 per cent in 1960's and it has been declined to 20 per cent in 1990's. The canals contributed about 37 per cent in 1960's and it has been reduced to 34 per cent in 1990's, though there is a marginal increase in area under canals in absolute terms.

Analisis of Canal irrigated area

There has been a marginal reduction in gross irrigated area under canal. Number of factors have contributed to the under utilization of the created potential: (i) inclusion of elevated upland in the project area;(ii) conversion of ayacuts for non-agricultural purposes; (iii) the original cropping pattern had undergone changes on account of the farmers preferences which led to increased consumption of water; (iv) the conveyance system below the sluice point having lost its original size and shape causes heavy transmission losses; (v) absence of field boothies; (vi) excessive drawal of water in the upper reaches; (vii) unauthorised irrigation, particularly associated with indirect ayacuts; (viii) poor maintenance of canals resulting in seepage losses; and (ix) sluices suffering damages cause leakages leading to wastage of water.

One of the significant changes that has taken place in the canal irrigation over the last three decades has been the changes in area under crops. It can be seen that the dominant crop under the canal irrigation has been rice. Despite decline in absolute area, rice has maintained its predominance throughout the period. The rice area has been declining at 0.19 per cent per year over the period. A major development has been the increase in area under sugarcane and groundnut. The sugarcane area has been increasing at 2.31 per cent per year over the period. The groundnut area has moved upward in the order of 2.15 per cent per year. However, cotton area has been stagnating in the canal system. A clear indication of more acreage coming under rice in late 1960s and early 1970s is mainly due to the modern rice technology which is complimentary to canal water. The decline in area under rice in 1980s might be due to low remunerative prices for rice and unfavourable weather conditions limiting water storage in the reservoirs during eighties. With the expansion in irrigation, the tendency of farmer has been to replace low value crops by substituting commercial crops like sugarcane. Groundnut has shown substantial increase in eighties due to special attention given to oilseeds. The stagnation in cotton area has been mainly due to the development of water logging and salinity in the canal system, pest and diseases and fluctuation in prices.

Analysis of tank irrigated area in Tamil Nadu

The growth rate in tank irrigated area has been estimated at -1.49 per cent between 1960 and 1990. This could also be compared with declining net tank area at the rate of 1.17 per cent. There is evidence from official data and academic studies that the tank irrigation system deteriorated over time.

Tank irrigation in parts of Tamil Nadu (non tank intensive districts) is decreasing in extent, though it has potential and is economically beneficial. Major factors causing the decline in gross tank irrigated area in tank non-intensive districts include deforestation, lack of soil erosion and siltation, all of which are related to environmental degradation over years. These problems accumulated over time reduced the effective storage capacity of the tanks in tank non intensive districts. Other factors include unauthorised cultivation, over grazing and foreshore encroachment which are related to increase in population densities. These were observed in both tank intensive and non intensive districts.

Rice area is growing at a rate of 0.02 per cent per year. In all the years, rice dominated other crops in the tank command area. Sugarcane area has been increasing at 1.25 per cent per year over the period of study. Increased demand for sugar, the increase in the number of sugar factories and the remunerative cane prices fixed by the Government have been the major factors responsible for this development. The area under groundnut is moving in the order of 1.38 per cent, however, the area under cotton is declining by 0.19 per cent. Changes in the cropping pattern in tank irrigations have taken place by substitution of groundnut for cotton and making the groundnut as the major commercial crop in the tank command area.

Analysis of well irrigated area in Tamil Nadu

The extent of gross well irrigated area is increasing from 1960 through 1990. The growth rate per year over this period is estimated at 1.05 per cent. This change can also be compared with increasing net irrigated area by wells at 2.50 per cent per annum. Well irrigation plays a dominant role in the state agriculture for a variety of reasons such as (i) decreasing scope for and increasing cost of surface irrigation development, (ii) increasing demand for more controllable water supply, created by HYV technology and (iii) low private investment in contrast to huge public outlay on surface irrigation. An important difference between surface irrigation and wells is that the former are public sources in terms of ownership and maintenance while the latter are largely privately owned and maintained. Wells in Tamil Nadu irrigate on an average one hectare each. The results indicate that an increase in the lagged mean rainfall by 10 mm brings up the water table by 0.21 metre (i.e. decreases the depth to water table by 0.21 metre) and an increase in number of wells by one thousand increases the depth to water table (i.e., pushes down the water table) by about 0.08 metre. The increase in depth to water table due to increase in number of wells is an indirect effect caused by the sharing of aquifers that have limited supply of water, among increasing number of wells.

Increasing number of wells (9 lakhs in 1960-61 to 18 lakhs in 1989-90) with decreasing water table has resulted in the stagnation of net irrigated area per well. Hence, the net area irrigated per well has decreased sharply over years from 0.80 hectare in 1960-61 to 0.60 hectare in 1989-90. To identify the factors influencing the area irrigated per well, a regression equation is estimated for well intensive, well non intensive districts, well inside and well outside the command. The negative coefficient for intensity of wells indicates a clear case of externality caused by digging additional wells in both the districts, even though the externality was much higher in intensive districts.

Private exploitation of underground water by numerous individual farmers has tended to result in an indiscriminate and unregulated proliferation of wells. Excessive exploitation of ground water leads to a permanent decline in the water table. More importantly the water yield from an existing well tends to diminish as the water table recedes. In the face of rising cost of digging wells and reduced water availability, the farm output is affected. Thus in an excessively exploited region, additional investment in new wells may prove counter-productive in the sense that additional area contributed by them may offset the existing area.

The other major reason for falling ground water is due to the increase in area under crops like sugarcane which consumes more water. The share of rice has been decreased from about 56 per cent in 1960-61 to about 38 per cent in 1989-90. However, sugarcane and groundnut have witnessed a rapid growth in area under well indicating commercial agriculture has been the important feature in this mode of irrigation. These two crops shared about 3 per cent each in 1960-61 and increased to about 10 per cent in 1989-90. However, cotton area is stagnating due to pest and diseases and wide fluctuation of prices.

Performance of the Irrigation Sources

The results of the analysis of the simultaneous equation system could give a broad conclusion about the factors affecting the performance of irrigation sources viz., canal, tank (system and non-system tank), well (inside and outside command). In the canal equation, total net irrigated area, fertilizer availability and current rainfall and rainfall lagged one year are the significant variables. As expected, these variables have positive sign. The result revealed that as total net irrigated area increases by 10 per cent, the net canal irrigated area is estimated to increase by 2.99 per cent per year. Since total net irrigated area has been included in the model as a proxy variable for irrigation investment, its impact is more on canal source. This is due to larger share of irrigation investment allotted to the development of canal source as compared to other sources. During the period from 1960 to 1990, the major and medium irrigation projects shared about two-third of total irrigation investment in Tamil Nadu.

The result also showed the importance of input supply particularly fertilizers in the expansion of net canal irrigated area. Holding all other variables constant, if fertilizer availability increases by 10 per cent, the net canal irrigated area increases by 0.25 per cent per year. This positive and significant relationship between fertilizer and canal source confirmed the fact that both are complimentary. This complimentary as well as the interaction effect between fertilizer and water is found to influence significantly the net canal irrigated area. Current mean rainfall and rainfall lagged one year influenced the net canal irrigated area positively and significantly. Since the catchment area of canal systems lie in the western ghats, the effect of time lag of rainfall on canal command area is reflected by the current and rainfall lag one year. Keeping all other variables constant, if mean current year rainfall and lag one year increases by 10 per cent, the net canal irrigated area expands by 0.47 per cent.

The simultaneous regression equation for net irrigated area under system tanks has a significant R-square value with total net irrigated area, population and North east monsoon rainfall and South west monsoon rainfall as significant variables. Holding all other variables constant, if total net irrigated area increased by 10 per cent, the net tank irrigated area under system tanks estimated to increase by 0.64 per cent. As expected, total net irrigated area has a positive and significant relationship, since it is a proxy for irrigation investment. In terms of a priori expectations, population variable has a negative but significant coefficient. In Tamil Nadu, for every 10 per cent increase in population, the system tank irrigated area decrease by 0.14 per cent. As expected, the encroachment, housing settlement and unauthorised cultivation have contributed to the negative coefficient of the population variable. Of the rainfall variables, the mean rainfall of North east and South west monsoon had a positive influence on irrigated area under system tanks. The net irrigated area is found to increase by 0.59 per cent if rainfall increases by 10 per cent. Mean rainfall of North east and South west monsoon explained the net area equation as this variable would assess the impact of both seasons on filling the tanks.

In the case of non-system tanks, three variables viz., total net irrigated area, population and mean rainfall of North east and South west monsoon were significant. The analysis also has shown that the impact of population on irrigated area is greater in non-system tanks than in system tanks. The non system tanks have not been properly maintained by PWD and local communities over years as compared to system tanks. Deforestation, lack of soil conservation measures in the catchment and siltation over the years had reduced the storage capacity of non-system tanks. As expected, the average of monsoon rain had higher effect on non-system tanks than system tanks. Non-system tanks have own catchment areas and are not linked to canals of rivers as in system tanks and hence they have to depend on monsoon rainfall for filling the tanks.

In the equation for wells inside command area, total net irrigated area, real agricultural GDP per capita lag one year, production index, fertilizer availability and infrastructural index have positive and significant influence on the expansion of area under wells inside command area. Holding all other variables constant, if total net irrigated area increases by 10 per cent, the net area under wells inside command area is estimated to increase by 2.19 per cent. It shows the impact of irrigation investment on the expansion of wells inside the command area. This expansion is greater than that of wells outside command area due to the better recharge of wells inside command, conjunctive use of well water with surface irrigation, interaction and complimentary effect of well water with other inputs such as fertilizer. If real agricultural GDP per capita lag one year increases by 10 per cent well area inside command is estimated to increase by 0.17 per cent. This variable is not significantly contributing to expansion of area under surface irrigations which are mainly by government sources. The change in area irrigated by wells inside is directly responsive to incentives viz., agricultural GDP per capita lag one year and production index. In particular, larger private source due to incentives indicate the intensity with which farmers have responded to the favourable economic conditions of the period. By the same token, fertilizer availability and infrastructural index could be interpreted. The impact of fertilizer availability is higher in wells inside command area than other sources. Because these farms have control over water supply, the input availability has induced the acreage under well inside command area.

The equation for wells outside command area had four significant variables viz., total net irrigated area, number of wells, mean rainfall of current and lag one year and mean rainfall of lag one year and lag two years. If total net irrigated area is increased by 10 per cent, the wells inside the command area would increase by 1.85 per cent. This variable is a proxy for irrigation investment and it showed the impact of investment on the expansion of wells outside the command area. The significant and negative coefficient for number of wells indicates that if number of wells increases by 10 per cent, the area under wells outside command area would decrease by 0.25 per cent per year and this might be due to the scarcity of water in this area. The result indicated that the digging additional wells would just share the existing command area and thus result in exploitation of ground water. The environmental variables, mean rainfall of lag one and two years had positive and significant influence due to the fact that the recharge of well water is mostly influenced by past years rainfall and time lag involved in the recharge of ground water.

Canal area allocation among different crops viz., rice, sugarcane, groundnut and cotton are estimated simultaneously. The results suggest that the constraint viz., gross canal irrigated area is the important variable in determining area allocation among crops. This constraint has a positive and significant influence on area allocation of selected crops viz., rice, sugarcane, groundnut and cotton. Holding all other variables constant, if gross canal irrigated area increases by one per cent, the gross irrigated area would raise by 0.76, 0.13, 0.04 and 0.03 per cent under rice, sugarcane, groundnut and cotton, respectively. This finding could suggest that an increase in canal irrigated area, has a higher and favourable effect on rice than other crops due to the suitability of canal water and delta region for rice cultivation rather than for other crops. In rice, cotton and groundnut equations, only gross canal irrigated area was significant. In sugarcane equation, the other positive and significant variables were its own price and infrastructural index. An increase in price of cane by 10 per cent would increase area under this crop by 0.34 per cent. Hence remunerative prices given to sugarcane might also be attributed to the three fold increase in area from 1960-61 (11,000 hectares) to 1989-90 (31,000 hectares). Holding other variables constant, an increase in infrastructural facilities by 10 per cent would increase sugarcane area by 0.15 per cent. This finding could reveal that the availability of infrastructure encouraged area under sugarcane. It also indicated the roads are needed for transportation of canes to the factories.

Area allocation under system tank among different crops viz., rice, sugarcane, groundnut and cotton were estimated simultaneously. The result could suggest that the constraint viz., gross irrigated area has a positive and significant influence on area allocation of rice, sugarcane, groundnut and cotton. The marginal share of rice is estimated at 0.65 and higher than the marginal shares of other crops. It may be due to the fact that system tanks provide continuous flow of water with low mineral content which permits uninterrupted rice cultivation year after year. System tanks have provisions to control over supply of water and hence there is no drainage and salinity problems. In sugarcane equation, price had induced acreage under this crop and so the area under sugarcane has increased from about 3 per cent (32,000 hectares) in 1960-61 to over 6 per cent (62,000 hectares) in 1989-90. Thus, the analysis reveals that gross canal irrigated area was the important constraint which determined area allocation decision in system tanks.

The results for non system tanks could suggest that constraint viz., gross irrigated area and environment variable viz., rainfall were the important variables in determining crop area under this system. The marginal share of groundnut is estimated at 0.44 and it is higher than other crops. Holding other variables constant, an increase in gross irrigated area under non system tanks by one per cent would increase the shares of rice, sugarcane, groundnut and cotton by 0.24, 0.03, 0.44 and 0.21 per cent, respectively. Since non-system tanks have poor storages, there existed always scarcity of water. Farmers have no control over supply of water. Hence they preferred the low risk crop like groundnut which demand comparatively lower amount of water. Current rainfall variable was significant in groundnut and cotton equation. As expected, seasonal rainfall determined the storage capacity of tanks as these tanks are not linked to canals. The storage capacity inturn determined the acreage under groundnut and cotton. Farmers in this production environment preferred groundnut and cotton during monsoon seasons due to limited water supply in non system tanks. Certain varieties of groundnut and cotton grown in this production environment are drought tolerant.

The results for wells inside command indicated that if gross well inside command area increases by one per cent, the marginal shares of rice, sugarcane, groundnut and cotton are estimated at 0.37, 0.48, 0.07 and 0.02 per cent. The findings could reveal the suitability of sugarcane in this command area. As expected, this crop requires larger amount of water (250 cm) than other crops and this requirement is met by wells inside the command area by co junctive use of surface and ground water. It is important to recognize the fact that a good deal of ground water that is being lifted by wells inside command is infact surface water which has seeped into the ground. In sugarcane equation, the other positive and significant variables were its own price and infrastructural index. Holding other variables constant, an increase in cane price by 10 per cent would increase area under this crop by 0.38 per cent. Remunerative prices given to sugarcane over this period might also be attributed to increase in sugarcane area under well irrigation from 37,000 hectares (3 per cent) in 1960-61 to 1,30,000 hectares (10 per cent) in 1989-90. An increase in infrastructural facilities by 10 per cent would increase sugarcane area by 0.26 per cent. Availability of infrastructure facilities encouraged area under sugarcane as roads are needed for transportation of canes to the factories. In cotton equation, the other significant variable was the pesticide availability. As larger amount of pesticide become available, the area allocated to cotton could increase which shows the importance of pesticides for cotton cultivation.

The results for wells outside command area indicated that if gross well outside command area increases by one per cent, the marginal shares of rice, sugarcane, groundnut and cotton are estimated at 0.24, 0.13, 0.26 and 0.28 per cent. The findings could reveal the suitability of cotton in this command area. This might be due to lower water requirement of cotton as compared to sugarcane and rice and this production environ-ment has no saline and drainage problems which are ideal for cotton cultivation. Farmers prefer groundnut next only to cotton as this crop is also a low risky crop under water scarcity situations. Remunerative prices given to groundnut and cotton also encouraged area under these crops as it is evidenced from the sign and significance of the coefficient for own price elasticities of groundnut and cotton.

The Long-run Analysis

The full model was simulated by expanding net irrigated area under each source by 10 per cent with all other variables are endogenous. Only important variables were considered for the longrun analysis. By comparing the results derived from this exercise with results from the base run, it showed larger elasticities with respect to constraints and resources. These larger elasticities illustrate clearly that farmers responded positively and strongly to the economic variables in the longrun.

Estimation of Productivity by Source

In the case of rice, the marginal productivity is higher in system tank and it is estimated at 3.87 tonnes per hectare. Canal ranks second (next only to system tank) with marginal productivity of rice at 3.52 tonnes per hectare. The result confirms the fact that system tanks are ideally suited to rice, where provision of a continuous flow of water with low mineral content. This system also permits rice cultivation without salinifying soil. In the case of sugarcane, the marginal productivity is higher in wells inside command and it is estimated at 126.73 tonnes per hectare. It may be worthwhile to interpret that sugarcane performance in wells inside command irrigation may be due to copius water supply at critical stages (protective role) and complimentary effect (productive and interactive roles) of well water with other inputs. The total water requirement of sugarcane is higher (250 cm) than other crops and it requires water throughout the year. Hence it is ideally suitable for cultivation in wells inside surface. The poor performance of other sources may be due to the scarcity of water in later stages of the crop. In the case of groundnut the estimated marginal productivity is higher for non system tanks (1.95 tonnes of pods per hectare). Groundnut requires moderate water supply without salinity and water logging. This type of environment is provided by non system tanks and wells outside command. The crop performance is also better in wells outside command as its marginal productivity worked to 1.74 tonnes per hectare. Canal is not so good for groundnut cultivation due to drainage and water logging problems. In the case of cotton, the marginal productivity is higher for well outside command with 4.26 quintals of lint per hectare. This crop requires moderate water supply (60 cm) without salinity and alkalinity. Drainage and water logging are not problems in wells outside command and hence this production environment is ideally suitable for cotton cultivation. The poor performance of cotton in canal is due to the fact that the qualitative character of canal production environment underwent a change over years.

Economic Efficiency

Economic efficiency has ranged from 0.50 in cotton to 0.60 in rice. This means that there existed 50 per cent potential for increasing cotton yield in all sources of irrigation by removing technical and allocative inefficiencies. The allocative inefficiency of cotton is higher in canal and it needed proper attention in this mode. Possibly, canals have had the problems of water logging and poor drainage contributing to lower allocative efficiency of cotton in canal system. Also rice is the main crop under canals as the water allocation pattern in the first season coincides with rainfall period.

Economic efficiency of groundnut has shown that productivity of groundnut could be increased by 49 per cent. Groundnut also needs proper attention in canals as this mode contributed more to allocative inefficiency. The poor performance of groundnut in canals might be due to poor drainage, salinity, alkalinity and water logging in canal environment. Economic efficiency of sugarcane has revealed that productivity of sugarcane could be increased by 42 per cent. Sugarcane needs proper water management in non system tanks to remove allocative inefficiencies since scarcity of water is higher in this node particularly at later stages of the crop. There existed a 40 per cent potential for increasing rice output. Allocative inefficiency of rice is the highest in wells outside command area as well as under non system tanks. Rice would need proper water management in these sources as these modes face the problems of water scarcity. The economic efficiency measures confirmed the results of area allocation model and productivity analysis, that adoption of rice in canals and system tanks, sugarcane in wells inside command, groundnut in non system tanks and cotton in wells outside command.

Determinants of Economic Efficiency

In rice equation, proportion of rice area irrigated in canal as technology variable has higher impact on economic efficiency. This might be due to the fact that productivity of rice has been relatively greater in canal and canal is also allocatively efficient in rice cultivation. Given the high yielding varieties of rice and modern technology, fertilizer applied during the production process shifted the production function of rice and increased technical efficiency and thereby economic efficiency. This impact has been captured by the resource variable, fertilizer, included in the equation.

In case of sugarcane equation, proportion of area irrigated in canal and proportion of area irrigated in wells inside command were positive and significant variables. These technology variables indicate the importance of composition of sources chosen for sugarcane planting in the determination of overall output and economic efficiency of the crop. In case of groundnut, proportion of crop area irrigated in non-system tank and proportion of area irrigated wells outside command were significant variables. As expected, the performance and productivity of groundnut were better in non-system tanks and wells outside the command. These sources were also allocatively efficient in groundnut cultivation. The economic efficiency of cotton has been influenced by proportion of area irrigated in non-system tanks and pesticide used. It may be recalled that an increase in the availability of pesticide significantly increased the area allotted to cotton. Given the higher yields of modern varieties of cotton, overall economic efficiency would increase as more inputs are applied. Wells outside command and non system tanks could have conducive production environment for cotton cultivation and so these sources were allocatively and technically efficient for cotton production.

Policy Implications

1. Tank irrigation system has been deteriorating over years due to socioeconomic, technological and administrative problems. There is a need for institutionalised arrangment for tank operation and regular and timely maintenance and repair. Formation of a Tank Irrigation Authority at the state level is recommended. This authority would train and supervise the water controllers and be responsible for improved tank management.

2. In the context of the unplanned proliferation that has already taken place, efforts should be made to regulate the sinking of wells in the future in the excessive exploited regions to avoid a permanent decline in water table. The collective use of wells under an institutionalised framework remains the best solution in these circumstances. It may have to be considered atleast in the tracts most seriously affected by over exploitation and falling water tables.

3. The performance analysis indicated that the irrigation investment should be prioritized based on the following rank order: Canals, Wells inside, Non system tanks, Wells outside and System tanks.

4. The results from the performance analysis also suggested that the decisions to expand net irrigated area were influenced by input availability and infrastructural facilities. The availability of inputs and infrastructures appeared to have been particularly important in the transition process and hence priorities should be given to the development of infrastructures such as roads and input supplies such as fertilizers and pesticides.

5. Based on the results of area allocation model, productivity model and allocative efficiency analysis, farmers should be encouraged to cultivate rice in canals and system tanks, sugar cane in well inside command, groundnut in non system tanks and cotton in well outside command with the help of extension agencies.

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