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RECURSIVE PROGRAMMING MODELS OF AGRICULTURAL DEVELOPMENT

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OUTLINE

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PART I. THE GREEN REVOLUTION: ITS SCOPE AND ANALYSIS

1. Introduction

The importance of a developing agriculture in an overall strategy of economic development derives from the fact that few nations have achieved high per capita incomes without first achieving substantial gains in agricultural productivity. This is especially true of the developing countries today, where growth depends heavily upon improving the performance of the agricultural sector, as it did in the earlier stages of economic growth of the developed countries. Even where the exploitation of natural resources such as petroleum or minerals has been possible in some low-income countries, the increases in per capita income have been confined to a very small segment of the total population. Such development, tied through export dependence to a developing country (often a previous colonial power) has led to social, cultural and economic dualism, and where these gains have not been accompanied by improvements in agricultural productivity, neither the income nor the lives of a majority of the people have been improved.

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*This paper is a revised version of an earlier paper SINGH [41] and draws heavily on three previous papers, SINGH and DAY [44] [45], and DAY and SINGH [9], and the author's dissertation SINGH [42]. The work reported here is part of a continuing collaborative effort with Professor R. H. Day to whom my personal debt is immeasurable. Errors remaining, however, are my sole responsibility.

Economic growth depends upon the performance of the agricultural sector because in developing countries with per capita incomes of less than $300, 40-80 percent of the total labor force and between 30-60 of the total GNP are accounted for by agriculture. In addition the non-agricultural sectors have to depend upon rural labor and capital resources for their growth in the early stages of growth and these are not forthcoming unless agricultural productivity and efficiency increase substantially. Furthermore almost 70-80 percent of the manufacturing industries in many developing countries are either based on raw materials from agriculture or produce materials for use in farm production. Since agriculture supplies the main raw materials to and the main markets for industrial output, low rates of growth of income and production in agriculture can seriously retard the growth of the non-agricultural sectors.

The importance of agricultural development is further enhanced by the dynamics of demography in the developing countries. A steady decline in mortality rates through improvements in public health and stable birth rates have led to population growth of 2 to 3 percent in many of these countries, with some growing even faster. These rates of population growth are nearly double the rates that prevailed in western Europe and Japan during their early stages of development.

The crucial question therefore is whether agricultural output and productivity can increase rapidly enough to meet the needs of the expanding population as well as satisfying the requirements of growth. It has been calculated that the supply of agricultural products must increase by 4 percent or more per annum in developing countries in order to meet the expanding domestic demand from population growth and income increases if major price inflation disruptive to growth is to be avoided. In some countries even larger gains are needed to provide more nutritionally adequate diets [47]. Agricultural output growth rates of 4-5 percent per annum are more than twice as high as those achieved in most developed countries for a period of a decade or longer. Can these rates be achieved?

The answer to this question in the first half of the decade of the sixties was negative. This pessimism reflected in part the poor performance of the agricultural sectors in the developing countries in the previous decade, but also partly the view, then widely held, that decision makers, especially peasants in the developing countries were tradition bound, "non-rational," "uneconomic" men limited by cultural and institutional restraints to any but insignificant responses to economic and market incentives designed to improve their lot. Myrdal's conclusions though derived from a study of South Asia [32], but widely accepted for most developing countries, correctly projected the situation as one of extreme pending crisis which would be out of control by the '70's, presenting serious problems of economic and political stability.

This extreme pessimism seems to have been exaggerated in the light of the evidence. In 34 of the 54 developing countries agricultural output expanded 3 percent or more per year; while 17 had growth rates of 4 percent or more demonstrating substantial progress.[1] What is more this rate of

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[1]Thus between 1950-68 annual growth rates exceeded 4 percent for such diverse countries as Costa Rica (4.2), Guatemala (5.0), Mexico (5.1), Nicaragua (5.9), Ecuador (6.0), Venezuela (5.1), Greece (4.6), Yugoslavia (4.6), Cyprus (4.9), Israel (9.3), Malaysia (4.1), Taiwan (4.4), Thailand (4.5), Senegal (4.3), and Sudan (4.1) [47, p. 11]. In addition regional development in West Pakistan, South Brazil, several states in India, Phillipines and Taiwan has matched these growth rates.

growth has accelerated recently in many developing countries. The most recent breakthroughs described as "the green revolution," and associated mainly with vast improvements in the biological conditions of production have substantially changed the outlook for overall economic development in the 1970's.

In addition, recent empirical work done in the L.D.C's has touched on another aspect of the problems of transforming traditional agriculture that lends further evidence to the possibilities of continued growth. This concerns itself primarily with the question alluded to earlier of whether or not peasants in traditional or near traditional agriculture respond adequately to opportunities made available by changes in market conditions. Until recently it was strongly felt that custom, tradition and authority were the major sources of the allocative and distributive directives in peasant agriculture, and that these constraints limited drastically both the use of traditional economic tools as well as market incentives to transform the sector. These recent studies have however shown that agricultural production in peasant and traditional agriculture in specific L.D.C's is responsive to economic incentives, especially when factors such as subsistence, adjustment lags due to uncertainty, quasi-fixity of capital stocks and the state of the arts and knowledge are accounted for.[2] Although the issue is far from resolved and although it is not necessary to contend that social and cultural directives play no part, what these growing number of studies do demonstrate is that models based

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[2]This latter view starting mainly with the pioneering work of SCHULTZ [40] and the alternative views are presented in WHARTON [49] where a series of articles on both sides of this controversy are available.

on the assumption of rational economic behavior and using the standard tools of economic analysis can be used effectively to explain, understand, predict and plan the process of agricultural transformation in these developing countries.

It is the purpose of this paper to show how one such tool--recursive programming--can be used to generate the past development of the agricultural sector in a selected region in a manner that can allow us to both understand the transformation process--an opportunity that is increasingly offered by the diverse nature of the regions where growth is occurring-as well as to effectively plan for and evaluate alternative policy measures designed to enhance this process. Part I of this paper briefly describes the importance of incorporating details we consider strategic to this transformation process, details without which such a model could not be operationally useful; part II presents the various components of the programming model designed to effectively incorporate these details; part III presents briefly the empirical results obtained for the Indian Punjab from 1952-65 for which the model was used to describe and understand its recent agricultural transformation; the paper concludes briefly with some of the data requirements and several possible policy applications for the model.

2. Details Strategic to the Analysis of Modern Agricultural Transformation in the LDC's

In order to analyze and understand the recent experience of agricultural development in the L.D.C.'s certain elements need to be incorporated if agricultural sector analysis is to become an operational tool capable of capturing the dynamic process of structural change and transformation. A brief examination shows that modern agricultural transformation in the L.D.C.'s has been mainly carried out in an environment in which (1) decision making occurs at the farm-level and involves firm-household units;[3] (2) technological elements, both biological and mechanical have been critical to the transformation process; (3) government participation either directly through the allocation of scarce resources or indirectly through established markets has substantially directed ("distorted") and channeled the development process; and (4) the development of the agricultural sector has had important implications for development elsewhere in the economy and vice-versa. These facts define the environment within which modern agricultural transformation is taking place.

This environment impinges so critically on the developmental process that we must attempt to incorporate these elements explicitly in our analysis. Though this list is not exhaustive it does reflect the philosophy of the model building underlying the effort that follows--that quantitative and mathematical models should attempt, as far as possible to incorporate those elements of the decision-making environment that are critical and strategic to the development process rather than assuming them away.

The strategic elements we wish to incorporate include (i) the details of firm-household interdependence and farm-level decision-making; (ii) the

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[3]Usually also under a regime of private ownership. Agricultural progress under state ownership has had a dismal record, and where partially successful has relied on decentralized decision making and economic incentives rather than centralized allocative and distributive mechanisms.

details of government policy actions and intersectoral linkages. The focus of the current modeling effort is the farm sector so that the first two sets of details are treated extensively while the importance of the last set is recognized but not incorporated fully.

2.1. Farm-Household Interdependence and Farm-Level Decision Making

Agricultural production in the LDC's, apart from commercialized plantation type production, is mainly carried out on privately owned and operated farms. There are several recognized elements of farm level decision making and production response that studies of agricultural development do not incorporate or incorporate unsatisfactorily. These were emphasized by DAY [4] and include:

1. The interdependence of outputs using common inputs (i.e., the multiproduct nature of the agricultural production firm);
2. Changes in both acreage and yield components in field crop production;
3. The relative interaction of input and output prices;
4. The rate of investment in factors fixed in the short run;
5. Uncertainty and adjustment over time;
6. Planned or programmed policy actions.

These interrelated categories have been incorporated in the empirical studies of production response in developed agriculture DAY [5] , DAY AND HEIDHUES [8], HEIDHUES [16] [17], SCHALLER [39], but their relevance to the study of production response in the LDC's has not been fully appreciated. These categories are not only relevant but crucial to the analysis of production response in traditional and near traditional agriculture.

In addition the interdependence of firm-household decisions and the special importance of subsistence production to the analysis of developing agriculture needs to be emphasized. The farm combines two fundamental units of microeconomic analysis--the household and the firm. Some attention has been given to the resulting interdependence in the economic analysis of developed agriculture HEADY et al. [15], DAY [5], DAY and HEIDHUES [8]. But while this interdependence is clearly of the essence in the analysis of developing agriculture, and defines the point of departure between the study of development in "traditional" and "modernized" agriculture, scant attention has been paid to its implications.[4]

The most important implication is that developing agriculture is often characterized by subsistence production where (i) the farm-household depends upon the farm-firm for its main items of consumption so that production is mainly carried out to meet these needs and not for the market and (ii) the farm-firm relies upon the household for its needs of labor and other production inputs.[5] As a direct result of this the response to market incentives is modified considerably as household consumption requirements act as a constraint on both the product mix as well as the marketed surplus. For a region as a whole this prevents crop specialization and dampens response to short run profitability in the absence of the

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[4]The exceptions have been NAKAJIMA [33] [34] [35] [36] and MELLOR [27] [28] who have both contributed significantly to a clearer theoretical understanding of this interdependence.

[5]See NAKAJIMA [35].

development of alternative sources of supply. This alternative depends upon the longer run development of the marketing, transportation and communication infrastructure, along with the processing and distributive channels for agricultural products, all aspects of a modernized agriculture unlikely in the LDCs.

The choices between leisure and income (amount of family labor offered for work), between present and future income (consumption and saving) and between retained and marketed output (amount of total income converted to monetary income) that the household makes, effects the choices between technologies (labor vs capital intensive), between production and investment outlays (variable and quasi-fixed inputs), between subsistence and commercial outputs (outputs for consumption and outputs for sales), and between owned and commercial inputs ("traditional" and "modern") that the firm makes. Under these circumstances it becomes difficult to differentiate the activities of the farm-household from the farm-firm. These considerations make it necessary to include the above elements of interdependence and especially "subsistence as a significant variable in its own right with important behavioral connotations for economics."[6] This interdependence between home consumption (in cash and kind), family labor inputs, farm outputs, farm investments, domestic savings, farm inputs, choice of technology and response to market incentives make it imperative that economic activities of the farming household be considered in an integrated

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[6] See WHARTON, C.R. Jr. [49] for several contributions on the role of subsistence agriculture in economic development.

framework if our analysis is to yield an understanding of the development process.[7]

Furthermore, we wish to reiterate that the real differences in the economic behavior of farmers in developing agriculture arise not from any lack of rationality but from differences in their means and the environment in which they arrive at their decisions. In this context we wish to emphasize the importance of uncertainty, learning and adoption and multiple goals that we wish to incorporate in the environment of decision making in developing agriculture.

That farming is a highly uncertain business is obvious even to a casual observer. That the degree of uncertainty is greater in developing agriculture due to a greater degree of dependence upon the environment, fewer means to control or circumvent it, greater disaster in case of failure, and the greater rate of innovation and change may not be so obvious. Accounting for uncertainty in some way is an imperative both for the farmer, and the economist if he is to understand the farmer's decisions. However, these are unlikely to take the form of Monte Carlo or other sophisticated rules currently in vogue among economic analysts. They are more likely to come closer to the rules of thumb procedures summarized as strategies of cautious optimizing, examples of which include the chance-constrained models

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[7]Consideration of these factors suggests that there are great similarities between the traditional farm and the traditional "household" of economic analysis. Both the household and the traditional farmer get incomes by utilizing their labor, both aim at the maximization of their utilities which are the function of income (and all goods) and the quantity of labor (or leisure). The essential difference is in their income equations; the income equation of the traditional farmer contains the production function, while that of the household does not.

of CHARNES and COOPER [2], the focus-loss principle of SHACKLE [38], the behavioral bounds of CYERT and MARCH [3], the safety-first principle of ROY [37] and the flexibility constraints of HENDERSON [18] and DAY [4] [5].

The breakdown of age old practices and habits takes time, partly because the supply of new inputs and their distribution must go through a development of their own, and partly because adjustments to profitable opportunities occur with a lag. These external constraints on input supplies and internal constraints due to the learning process and lagged adjustments assure that the impact of new technologies, following their introduction, will be distributed over time. These facts about learning and adoption behavior should clearly be incorporated in any analysis of development.

There is a growing realization that economic decision making involves a multiplicity of goals and that single criteria like profit maximization are inadequate in describing the decision process. Furthermore, all goals do not have an equal priority and are often ranked according to a set of preferences. This has a very special significance for peasant agriculture where food requirements to meet basic survival needs or safety criteria may be placed ahead of profit maximization. Such ordering of goals, evident even in the most advanced industrial organizations should be included in the analysis if possible.

All these elements, the interdependence of firm-household decisions, the existence of uncertainty, learning, adoption and multiple goals play a role in the study of developed agriculture, but the degree of their importance and impact upon the environment, and the means, manner and circumstances of their consideration in the decision process differ for a study of agricultural development in the LDC's.

2.2. Technology and Technological Change

The most strategic role in the modern transformation of traditional agriculture is assigned to technological change. Although there is agreement about its role there is little agreement on what constitutes technology and how to measure it. The neoclassical theory of the firm is primarily based on twice differentiable production functions which assume a single output and represent a given technology. Technology in agriculture is really characterized by multiple outputs, and during periods of transition (which are the main focus of our interest), by multiple technologies. Activity analysis as developed by KOOPMANS [25], LEONTIFF, et al. [26] and applied by many investigators allows us to represent all three of these characteristics in great detail providing a means of identifying and measuring technology.

Anyone who has directly observed traditional agricultural production is impressed by the fact that it is a complex phenomenon with hundreds of tastes, being performed by many possible combinations, requiring detailed knowledge of soils, topography, climate and an ability to distribute a variety of scarce resources over time, and crop use. These choices are increased when technological change occurs. The most important components of technological change that can be quantitatively analyzed include new material inputs (water, inorganic fertilizers, herbicides, pesticides, fungicides), new outputs (new crops, improved varieties), new implements and power sources (steel implements, powered implements, and electric and diesel engines as sources of power) and new cultural practices (multiple cropping, new tasks such as transplanting, contour or row planting, deep furrowing and terracing). All these involve in a fundamental way the factor-product, factor-factor- and product-product relationships that are important to an analysis of technology and technological change. Not all the details with which a farmer himself must contend need to be incorporated, but many of them are important. Only by representing major technological alternatives in an activity analysis framework can we expect to effectively understand and analyze technology and technological change in agriculture.

Furthermore, going along with SCHULTZ [40] in stressing the importance of new technologies if agriculture is to be shifted from its traditional state of equilibrium, we wish to examine most explicitly their impact. Activities representing new and non-traditional technologies along with traditional activities, incorporated within the framework of a set of possible farm operations enables us to analyze the many choices describing the transition from traditional to modern agriculture.

2.3. Government Policy Actions and Intersectoral Linkages

While keeping our focus primarily on the farm sector we recognize that government policy actions can alter the environment of farm decision making and that important intersectoral linkages exist. Government policies can be designed to accelerate or control the development process or achieve a specific set of goals.

We view policies as affecting the farm sector through (i) a direct control of scarce economic and physical resources for allocative or distributive purposes, (ii) existing markets by subsidizing or supporting input and/or output prices and (iii) changes in the social infrastructure that reduces the cost of farm production or increases (in quantity and quality) the resource endowments of the farm sector. Examples of direct controls include quotas on production, government purchases or release of stocks, import and export controls and the direct distribution of farm inputs and outputs. Examples of policies working through markets include price supports and subsidies, minimum wage laws,and subsidized interest rates to name only a few, while examples of policies that change the infrastructure include land reclamation and settlement, irrigation, electrification, communication and transportation projects and the development of research, education and extension, market and distribution agencies.

In explicitly accounting for government policy actions, policies are seen--either as affecting (i) the payoffs (opportunities) or their expectations or (ii) the resource endowments (constraints) facing decision makers in the farm sector.[8] Although this allows most policy actions to be affectively treated, the real problem is to translate the effects of a specific policy on specific payoffs and endowments in order to realize their quantitative dimension, a no mean task in itself.

We have mentioned the external constraints imposed by the limited availability of non-farm inputs such as implements, farm machinery, fuels and fertilizers, indicating that the development of the agricultural and

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[8]Policies can also affect the farm sector through their impact on non-farm commodity and factor markets and the development of the non-farm infrastructure. Part of this impact is captured through linkages with the non-farm sector, but their detailed treatment will have to await a more general multi-sectoral model of development, a task towards which the current farm sector model is an important and necessary step.

other sectors is interdependent.[9] The most important intersectoral linkages include (i) the demand for farm outputs by the non-farm and export sectors which affect the prices of farm outputs and which act as a constraint upon the expansion of farm output, as well as convert the potential demand for non-farm inputs into actual demand by providing the markets for commercial sales; (ii) the supply of non-farm inputs such as fuels, fertilizers and machinery whose availability and supply price crucially determine their adoption; (iii) opportunities for non-farm employment that compete for labor as well as provide supplementary income transfers to the agricultural sector, (iv) opportunities for non-farm investments that compete for capital (private and public) and may restrict the flow of credit to the farm sector; and (v) the demand for non-farm consumer goods on part of the farm sector, that given its size and contribution to employment and output, provide the main markets for the expansion of the non-farm sector in most LDC's given the inelasticity of the export markets.

Some of these linkages occur indirectly through market prices and some occur directly through physical and behavioral limitations on the use and availability of resources. Hence even in models whose primary focus is on the development and planning within the farm sector these linkages must be accounted for.

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[9]This interdependence has been continually emphasized (see B. JOHNSTON and J. MELLOR [23] and B. JOHNSTON and P. KILBY [22]) and is the primary focus of the general systems simulation approach to agricultural sector analysis developed by G. JOHNSON and his associated [20].

PART II. A RECURSIVE PROGRAMMING MODEL OF AGRICULTURAL DEVELOPMENT

Having stated our fundamental premise that agricultural development as it is taking place in the LDC's can be fully understood and effectively planned only if we account for a host of technological, decision-making, policy and intersectoral details, we now attempt to construct a recursive linear programming model that explicitly attempts to incorporate them.

Since the complexity of these details is so vast, and the variety of their applications, at least in principle unlimited, it is most difficult to construct a general model that would apply to all types of agricultural transformations underway in the LDCs. Each specific case has it's own technologies that are critical, policies that are designed for specific ends, and intersectoral linkages of paramount importance, but which may be of little relevance elsewhere.

In order to make our model concrete we discuss its application to a given region--the Indian Punjab--that has recently experienced a vast agricultural transformation evidenced by high rates of growth of output, a rapid transition from subsistence to commercial production, a rapid adoption of the "green revolution" package of seeds, water and fertilizers, with changes in farm technology, through rapid mechanization and structural changes in the composition of inputs.[10]

By specifically setting out the components of the model as applied to the Punjab we will also be able to discuss the results of the model

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[10]This region has experienced growth rates in excess of 5 percent per annum. See HENDRIX and GIRI [19], A. S. KAHLON, _et al_. [24].

and some of their implications. However, it is our contention that the general methodology can be appropriately tailored to examine agricultural transformations elsewhere since the basic theory and components remain unchanged, only their relative importance, detail and specific data vary.

1. The Model[11]

The Punjab model is made up of six basic components. These are (1) an annual objective function measuring the expected revenues from crop sales, the costs of purchased and hired inputs and an investment charge for resource augmenting investment decisions; (2) a technology matrix representing the input-output structure of home and cash consumption, farm production, investment, sales, purchase and financial activities; (3) a "technical" constraint structure representing regional resource and financial limitations; (4) a "behavioral" constraint structure representing adaptive, "safety-first" limitations for protection against mistakes of cropping and investment choices, and representing drags on investment due to "learning" and "unwillingness to change;" (5) a set of feedback functions that relate the parameters of the current programming problem to previous decisions, giving the model it's dynamic character; and (6) exogenously given input and output prices, regional supplies of land and labour resources and exogenously estimated subsistence and cash consumption

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[11] For the general methodology of recursive linear programming models see R.H. DAY [5], [7]; for its application to regional agriculture see R.H. DAY [4] and [5] and T. HEIDHUES [16] [17]. For a theoretical statement and validation of the model in this study see R.H. DAY, and I.J. SINGH [9]. For a detailed exposition of all the model components see I.J. SINGH [42].

requirements. We shall first describe the activities that are assumed to be the basic objects of choice by farmers in the region. We then review each of the major model components.

2. Regional Farm Activities

Farms in the Punjab engage mainly in the production of field crops both for home consumption and commercial sale.[12] The farms in the region are fairly homogeneous with respect to soil, climate, topography, farm size, resource distribution and tenure conditions.[13] The field crops included in the model are sown in two cropping seasons--the rabi (winter) season which extends from the beginning of October to the end of April and the kharif (summer) season which extends from May to the end of September. The main rabi crops included in the modėl are wheat, gram, barley, and green winter fodders (mainly Egyptian and Indian clovers), while the main kharif crops included are cotton, maize, rice, groundnut, and bajra (spiked millets). An annual crop of sugarcane which extends over both the seasons is also included. New and improved varieties of wheat, cotton, maize, rice and bajra are included along with the traditional varieties. These

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[12] Subsistence production (not to be confused with subsistence consumption) is due to the predominance of two characteristics: (1) a large proportion of the farm output is retained for consumption by the household and (2) a large proportion of the total labour input on the farm is provided by family labour. Subsistence production characterizes peasant agriculture in most of the LDCs. See C. NAKAJIMA [48] and C. WHARTON, JR. [35].

[13] To assure that exact aggregation conditions are approximately satisfied the regional analysis is further limited to the five central districts (Amritsar, Kapurthala, Jullunder, Ludhiana and Patiala) of the Indian Punjab.

crops are considered under both irrigated and unirrigated (rainfed) conditions and accounted for over 96 percent of the total cropped area in the state.

Since field crop production is carried out by a sequence of tasks, and each task can be performed using a specific power-implement combination, a set of intermediate production activities are included in order to analyze the technical choice available to farmers in the region. Specific tasks for which alternative operations are analyzed include land preparation (by bullocks and tractors), irrigation (by canal, persian wheel wells and tube-wells), harvesting and threshing (manual and bullocks vs. tractor powered harvester and thresher), transportation (bullock cart and tractor-trailer) and sugarcane processing (by bullock drawn and diesel powered cane crushers). The choice between alternative mechnaical ways of performing a task depends upon the relative costs of the operations, the relative availability of resources used by the operation and upon the adoption of new power sources and their availability.[14]

The biological components of technology are incorporated by another set of intermediate production activities that allow for crop fertilization. By fertilizing an acre of any crop at a given level, the model allows an improvement in the "base" yield by an incremental amount if additional fertilizing costs justify it. Several levels of fertilization

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[14]The use of these intermediate production activities allow us to analyze the mechanical components of technological change that include new power sources and implements being adopted in the region. For a detailed task by task breakdown of the mechanical components of technology in the Punjab see I.J. SINGH, R.H. DAY and S.S. JOHL [46] and for an exposition of how to incorporate them into programming models see R.H. DAY [5] and I.J. SINGH [42].

are allowed for each crop variety and these activities compete for regional availability of chemical nutrients.[15]

The production activities as a group $(j \epsilon P)$,[16] which include land preparation, planting, cultivating, fertilizing, harvesting, processing and transporting, are structured to represent the double cropping system prevalent in the Punjab and to accommodate the prevalent and potential alternative water and nutrient mixes and alternative power implement combinations.

Household activities $(j \epsilon H)$ include subsistence, food consumption, commercial consumption and labour supplying on and off farms. Subsistence activities describe the home consumption of farm produced commodities. They use wheat, gram, maize, rice and processed sugarcane (gur) as inputs

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[15] "Base yields are expected yields without fertilization and are estimated from historical data, while the yields expected at various levels of nutrient application are estimated from yield-fertilizer response functions fitted to fertilizer field trial data. See I.J. SINGH [42].

[16] In the rest of this section the following notations are used to make the exposition more convenient and concise:

Activities are assumed to be linear, finite in number and their levels X_j, $j \epsilon X$ are measured for the regional aggregate. Constraining factors are identified by an index $i \epsilon Y$. The technical coefficients b_{ij}, $i \epsilon Y$, $j \epsilon X$ are assumed constant over time and all technology is assumed to be embodied. Positive (negative) coefficients mean a given factor is a net input (output); a zero coefficient indicates a factor not involved in the activity in question. Limitation coefficients C_i, $i \epsilon Y$ are also defined at the regional level; positive (negative) coefficients are associated with upper (lower) bounds on activity combinations, zero coefficients with balance constraints.

I am indebted to Professor R.H. Day for introducing me to this time saving notation.

for direct household consumption, reducing the amount available for commercial sale at harvest prices. The model also includes the production of fodder crops for the maintaining draft animals. Fodder input coefficients are based on daily minimum fodder requirements per animal and additional fodder requirements when the animals are worked.[17]

Purchase activities, $(j\epsilon B)$ include the purchase of variable inputs such as fuel, fertilizers, improved seeds, feed concentrates and government controlled canal water, while sales activities $(j\epsilon S)$ are included for each final crop output sold on the market.

A set of financial activities $(j\epsilon F)$ include saving, borrowing and debt repayment. After meeting cash expenditures on fixed farm inputs and household consumption, the farm-firm has a choice of using its remaining capital for farm inputs or depositing it in the bank. The relative amount of money capital invested in each alternative depends upon the internal rate of return and the time deposit rate respectively. The farms are also assumed to have access to short term loans advanced for a single period at varying interest rates which has to be paid at the end of the production period.

Investment activities $(j\epsilon I)$ include land improvement and development and the purchase of capital goods that replace worn out machines and add to available capacities in new power sources such as tractors, tubewells, threshers, harvesters and cane crushers.

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[17] Both household food consumption and fodder consumption by draft animals are considered as annual costs of maintenance for owned resources that are essentially fixed in the short run. These subsistence requirements are a first order objective before farmers begin to minimize short run cash costs. For a more complete exposition see R.H. DAY and I.J. SINGH [9].

3. The Constraint Structure

Farmers' choice activity levels are constrained by resource, financial, subsistence, and behavioral limitations. These are represented at the regional level by a system of inequalities for each crop year

(1) $\Sigma_{j\varepsilon X} b_{ij} x_j(t) \leqq c_i(t),\ i\varepsilon y,\ t = 1,\ldots,\theta,$

in which y is an index set identifying specific constraints, the b_{ij} are input-output coefficients (negative for outputs, positive for i^{th} inputs and zero when the i^{th} items is not involved in the j^{th} activity), and the $c_i(t)$ is the "resource" availability for year t. Four subsets of constraints are briefly described now.

3.1 Resource Constraints

Resource constraints include constraints upon the regional availability of variable, quasi-fixed and fixed inputs.

Variable input constraints include (i) constraints on labour $(i\varepsilon w)$ where exogenous regional supplies of rural wage (hired) labour are augmented by household activities which supply family labour by season and which in turn are limited exogenously by the number of farm families and the labour in them; and (ii) constraints on purchased inputs $(i\varepsilon b)$ such as fertilizers (in nutrient equivalents of nitrogen, phosphorus and protein), fuel, electricity and pesticides whose regional supplies are exogenously specified by either government controlled distribution or market factors and iii) constraints on animal draft $(i\varepsilon a)$ specified by the regional stock of work animals.

Constraints on quasi-fixed inputs include limitations on machine capacities ($i \varepsilon m$) of various power sources such as tractors, tubewells, threshers and cane crushers, limited by invested (depreciated) capacity but which can be augmented by investments.

Fixed regional resources include constraints on land supplies of various quality ($i \varepsilon l$) including exogenously given supplies of irrigable and rainfed land and canal irrigable area for both the rabi and kharif cropping seasons.

The supplies of labour, animal draft and machine capacities are considered during seven different periods in the cropping season. The supply of seasonal labour is treated as a three step staircase function with family labour available at a zero "reservation price", the hired labour available at the rural wage rate, and additional hired labour available from nearby urban centers at one and a half times the rural wage rates. The supplies of all three categories of labour are assumed to grow at an exogenously given rate equal to the rate of growth of the rural population in the state.[18]

3.2 Financial Constraints.

Financial constraints ($i \varepsilon f$) are of two types: (i) a constraint upon the amount of working capital available whereby the cash use is restricted by the cash generated from sales, savings and non-farm incomes in the

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[18] The use of family labour is given a zero "reservation price" because its annual cost of maintenance is explicitly incorporated through household subsistence activities. For an alternative treatment of family labour and the use of step functions to represent demand and supply schedule constraints in large l.p. models, see DULOY and NORTON [11] and GOREUX et al. [12].

previous year less cash outlays for production inputs, cash consumption expenditures and debt repayment of previous year borrowings; and (ii) a constraint upon the amounts of short-term borrowings at various rates of interest.[19] Current credit availabilities are related to previous years cash sales and operational expenses.

3.3 Subsistence Constraints

The subsistence constraints (iεs) are of two types. The first describe exogenously estimated lower bounds on the amount of farm outputs required for household consumption, requirements which have to be retained before outputs are sold. The second describe a lower limit on the amount of fodders required for maintaining and using draft animals. Retained consumption requirements in their turn depend upon past consumption and output levels of the subsistence crop.[20]

3.4 Behavioral Constraints

Behavioral constraints (iεr) include crop flexibility and adoption constraints. Crop flexibility constraints place upper and lower bounds on individual crop acreages in any given year. They are adaptively defined below and represent a "rule of thumb" approach to risk programming.[21]

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[19] In this study the supply of credit is also treated as a four step staircase function with half the total credit supply available at 7%, another quarter at 10% and the last quarter at 12.5% nominal rates of interest. Additional unlimited supplies of credit are available from outside the region, but their opportunity cost is assumed to be 30%.

[20] See SINGH [42].

[21] For a use of flexibility constraints see R.H. DAY [5], J.M. HENDERSON [18], N. SCHALLER [39], T. HEIDHUES [16] and I.J. SINGH [42]. For their theoretical justification and implications see R.H. DAY [6] and R.H. DAY, et al. [7]. The consumption-flexibility constraints provide the model with a set of inequalities that restrict the range of cropping patterns to ones that (1) provide farm outputs for household consumption, (2) provide sufficient fodder for the farmers draft animals and (3) do not permit "unreasonably" large acreages for "unusually" profitable crops on the basis of but one year's information. See also C. GOTSCH [13] for a similar use in a model of W. Pakistan agriculture, and T. A. Miller [29] for an evaluation of alternative formulations.

Adoption constraints account for the fact that when technologies or crop varieties are introduced, even if they are profitable and remain so, they are not adopted immediately. Both investments in new power sources and growth in the acreage of new crop varieties are constrained by an upper bound to express such factors as learning, experience, cautious adoption and innovative behavior. These adoption constraints are also adaptive and lead to S-shaped diffusion patterns.[22]

4. The objective Function

The objective function which represents the expected net cash returns to fixed farm resources for each year is

(2) $\Pi(t) = \Sigma_{j \varepsilon X} a_j(t) x_j(t)$

where

$a_j(t)$ = the expected price per quintel of the appropriate cash crop when j is a sales activity;[23]

$a_j(t)$ = average regional time deposits rate when j is the savings activity;

$a_j(t)$ = the nominal rate of interest when j is a borrowing activity;

$a_j(t)$ = the current variable cost of the appropriate production input when j is a purchase activity (seeds, manure, chemical fertilizers, pesticide, animal draft, fuel, lubricants, repairs, canal water charges and labour costs);

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[22]Such adoption paths are not peculiar to agriculture but are also evident in industrial investment behavior. See R.H. DAY et al. [7].

[23]The sales activity pay off coefficients are assumed to be lagged values for simplicity. More complete price expectation models have also been investigated. See M. MUDAHAR [30] and G. MULLER [31].

$a_j(t)$ = an investment charge on the purchase of new power sources when j is an investment activity, (such as tractors, diesels, threshers, etc.) estimated on a straight line depreciation basis (i.e., $a_j(t) = p_j(t)/L_j$, where $p_j(t)$ is the current purchase price and L_j the use life of the j^{th} investment good).

This objective function is maximized period after period, subject to the constraints appropriate for each period. It represents farm decisions as being determined by short run profit maximizing but subject to the satisfaction of various constraints some of which represent fulfillment of the "high order goals" of subsistence consumption, safety and cash consumption.

5. <u>Feedback Functions</u>

The inclusion of feedback "outside" the optimizing model is what distinguishes recursive from ordinary linear programming problems. The elements of explicit feedback incorporated in the model are: (1) the adaptive flexibility and adoption and adjustment constraints that define producers adjustments and response to risk, uncertainty and learning over time and which depend upon the previous year's activity levels; (2) machine and power capacity constraints that depend on past investment levels; (3) cash availability in its dependence on past sales; and (4) credit limits in their dependence on current debts and assets which in turn depend on past borrowing and debt repayment activities.

The adaptive flexibility, adjustment and adoption constraints take the general form:

(3) $C_i(t) = \gamma_i[C_i(t-1), X^*(t-1)], i\varepsilon R$·

for constraint $i\varepsilon R$, the subset of behavioral constraints, where γ_i is the i^{th} explicit feedback function--a flexibility, investment adjustment or investment adoption constraint as the case may be--and where $X^*(t-1) = (X_1^*(t-1),\ldots,X_n^*(t-1))$ is the vector of activity levels chosen the preceding year.

The machine and power capacity constraints take the general form:

(4) $C_i(t) = (1 - \delta_i)C_i(t-1) + X_{j_i}^*(t-1), i\varepsilon M , j_i\varepsilon X$

where δ_i is the depreciation rate for the i^{th} machine and $x_{j_i}^*(t-1)$ is the investment in the i^{th} machine in the preceding year. There is of course one investment activity $j_i\varepsilon X$ for each machine capacity $i\varepsilon M$.

Current working capital availability depends upon past sales, cash outlays on consumption and production, non-farm incomes and past borrowings and savings.

$$(5) \quad C_i(t) = \Sigma_{j\varepsilon S}a_j(t-1)X_j^*(t-1) + \bar{y}(t-1) - \Sigma_{j\varepsilon B}a_j(t-1)X_j^*(t-1)$$

$$+ \Sigma_{j\varepsilon F}a_j(t-1)X_j^*(t-1) - \Sigma_{j\varepsilon H}\bar{X}_j(t-1) \quad ; \quad i\varepsilon F$$

where $\bar{y}(t-1)$ and $\bar{X}_j(t-1)$ are exogenously estimated levels of non-farm cash incomes and household case expenditures;[24] $j\varepsilon S$ is the j^{th} sales activity and $a_j(t-1)$ its unit payoff in the preceding year, $j\varepsilon B$ are purchasing activities with $a_j(t-1)$ their unit costs and $j\varepsilon F$ are borrowing or saving

[24]Though household cash expenditures are estimated exogenously in this study, it is possible to treat them endogenously as a function of net farm incomes generated by the model. However lack of data made it difficult to estimate these relationships.

activities and $a_j(t-1)$ the interest rates--positive for saving and negative for borrowing--and where $X_j^*(t-1)$ are the levels of the respective activities in the preceeding year already estimated by the model.

Borrowings are assumed to be limited by gross sales in the previous year

$$(6) \quad \sum_i C_i(t) = \beta \sum_{j \varepsilon S} a_j(t-1) X_j^*(t-1) \ , \quad i \varepsilon F$$

where $C_i(t)$ are the borrowing constraints for year t and β the "borrowing coefficient" so that the sum of all borrowings cannot exceed a fraction of previous years gross sales.[25]

The remainder of the constraint coefficients depend on exogenous data. The availability of regional land, labor and animal draft resources are estimated exogenously from census data and projected by means of their time trends. Hence, we may write generally

$$(7) \quad C_i(t) = \left\{ \begin{array}{c} c_i^o(t), \ t = 1, \ldots \theta \\ \text{or} \\ f_i(t), \ t = 1, \ldots \theta \end{array} \right\} \quad i \varepsilon E$$

where E is the subset of right-hand-side limitation coefficients involving land,animal draft and labour resource capacities, (E = WULUA) where $f_i(t)$ is the time trend for the i^{th} resource and where $C_i^o(t)$ is the "observed" capacity in year t . The observed land capacities were available from regional data but animal draft and labour resources had to be extrapolated on the basis of a time trend between the two census years, since annual data were unavailable.

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[25]The "borrowing coefficient" is usually a rule of thumb criteria followed by credit institutions thus defining a maximum credit limit beyond which they won't extend themselves.

6. Model Summary

The principles which we assume reflects farmer's decision making in our model can be summarized as follows:

(1) Farmers first determine subsistence needs;

(2) Their willingness to adopt new practices is related to exposure and this can be measured by the current amount of production already involving the new practice;

(3) Farmers also limit investments in a given capital goods according to a flexible accelerator type of bound to limit risks of investing "too much";

(4) Farmers attempt to distribute marketing risk by choosing a "portfolio" of crops. Changes in the "portfolio" are limited by "rule of thumb" percentages that approximate more sophisticated risk programming models;

(5) Farmers' cash consumption depends on cash income;

(6) Anticipated prices are based on recent market experience;

(7) Given these considerations farmers allocate their resources so as to maximize anticipated net cash returns from farming.

The model is computed by setting up and solving a linear programming problem (1)-(2) for a given initial year. The optimal solution vector and the resource constraint vector are then used to estimate a new set of constraints using the feedback functions (3)-(6) and exogenous data or trends (7). A new objective function is obtained for (1)-(2) and the new linear programming problem is set up and solved for the next year. The complete model consists of a sequence of linear programming programs; the parameters of each member in the sequence depends on the solutions to the preceding problem in the sequence and on various exogenous data. Such a model is an open recursive linear programming model DAY [5 , Chapter III]. It describes the aggregate farm decisions by sequence of "rolling plan" or "recursive programs" rather than by optimal trajectories computed from a long horizon, dynamic programming model.

We use this model to estimate resource use, production patterns, technological change, factor productivity and factor proportions for the Central Punjab for the years 1952-65. How well the model performs depends upon its ability to capture the historical trends for these variables over the period for which the model was estimated. Detailed data of the sort needed to test such complex models is usually not available, nor do we have a complete theory for their evaluation.[26] However, a detailed comparison of the model estimates for crop acreages suggested that the model represented the economic history of the region fairly well. A complete analysis of the model evaluation is contained in DAY and SINGH [9]. We now turn our attention briefly to some of the specific model results and policy and analytic applications of this and similar models.

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[26] Even for simply dynamic models for which the structural and econometric specifications are fully known evaluation criteria have not been fully developed (see P.J. DHRYMES <u>et al.</u> [10]). For dynamic simulation models of the type used in this study, for which the structural and econometric specifications violate many of the assumptions of classical statistical inference, even greater insurmountable problems to evaluation exist. See S.R. JOHNSON and G.C. RAUSSER [21] for a discussion of the pertinent issues in model evaluation.

PART III: MODEL RESULTS AND POSSIBLE APPLICATIONS

1. Model Results: Central Punjab (1952-1965)

Some of the model results for the Central Punjab from 1952-1965 are displayed in figures 1-6.

Figure 1 shows the observed and predicted cropping pattern for the four most important crops in the region. Besides being able to predict crop acreages, the advantages of a model that is able to simultaneously account for multiple outputs in a double cropping system is clearly demonstrated by its ability to capture the time path of a complex cropping pattern with reasonable accuracy.[27] The main prediction errors arise from the wheat-gram combination which is difficult to predict as well as observe because a wheat-gram mixture is often planted to unirrigated acreages in the rabi season. If the rainfall is adequate the wheat requiring more water is allowed to grow, while if it is inadequate, the gram is allowed to mature to harvest.

The most important aspect of the model (if we can attest to its ability to predict observed behavior) is its capability in augmenting our understanding of the transformation process, given the observed values of the exogenous data (input and output prices and regional supplies of land and labor), by presenting a detailed quantitative chronicle of farm activities and their outcomes as they may have occurred, even where regional data are unavailable.

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[27] The model included ten major crops besides fodder crops in a double cropping system.

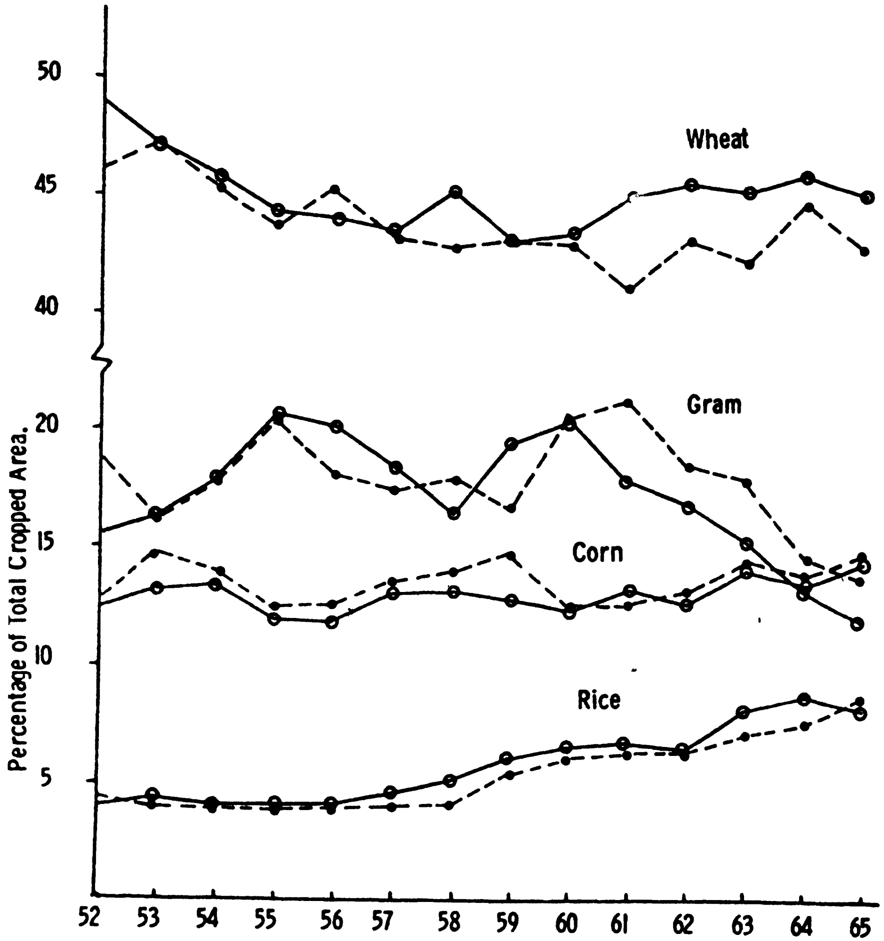

Fig. I. Observed & Predicted Cropping Patterns in Central Punjab (1952-65).

——— Observed. -------- Predicted.

Source: [42, Table 37]

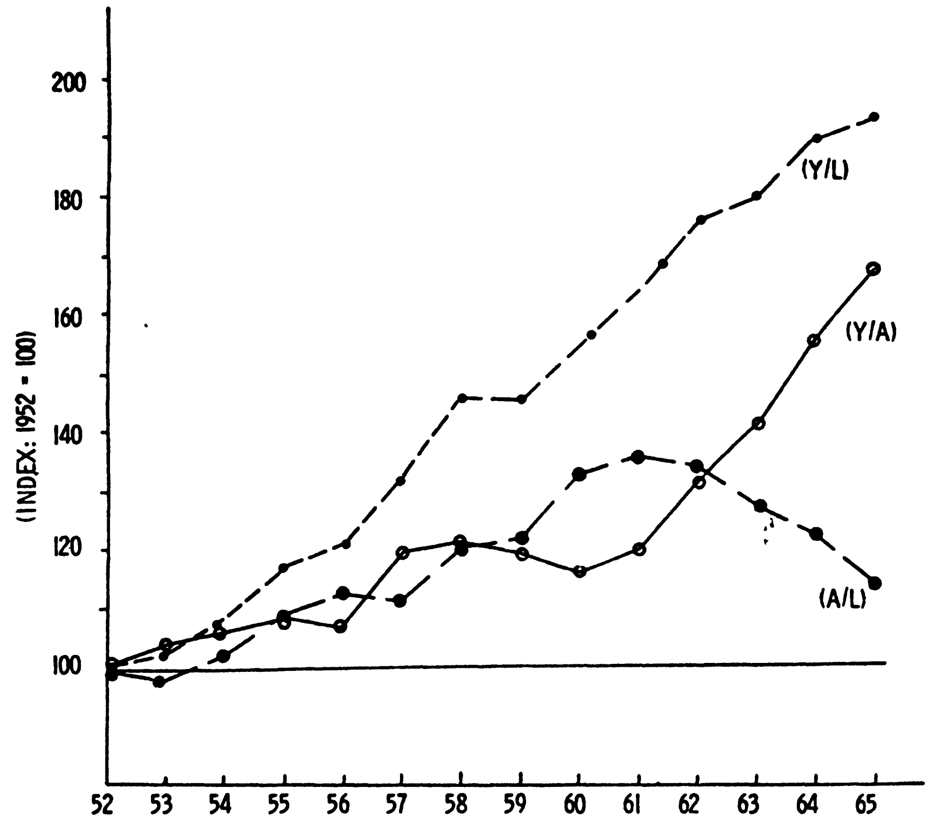

Fig. 2. Aggregate Labour Productivity (Y/L), Output per Acre (Y/A) and Land - Labour Ratio (A/L) in Central Punjab (1952-65)

Source: [44, Tables 30, 31] : MODEL RESULTS.

Such a chronicle, provided in detail elsewhere [44], correctly captured the main features of the agricultural transformation in the Punjab during the period which included:

1) a rapid growth in output and productivity,
2) a rapid adoption of the "green revolution package" (new seeds, fertilizer and water) specially after 1960,
3) rapid, task specific mechanization, in an apparently aggregate labour surplus environment,
4) a structural change in the demand for and the composition of inputs and
5) an increasing commercialization of farm production through forward (output) and backward (input) linkages with the non-farm sector.

Following HAYAMI and RUTTAN [14] in figure 2 we illustrate the growth of aggregate labour productivity (Y/L) predicted by the model, by decomposing it into two components, the aggregate output per acre (Y/A) and the land-labour ratio (A/L) to account for different "types" of technological change. It is apparent that the Punjab experienced both biological (labour intensive or land-saving) and mechanical (labour saving) innovations over the period, the former associated with an increase in (Y/A) and the latter with (Y/L). The major change has been in the adoption of the green revolution package, but this has also been accompanied by the adoption of labour saving task specific mechanization. The decline in the land-labour ratio after 1960 is directly correlated with the adoption of new varieties and increased yields per acre thus leading to an increase in the demand for labour at a rate faster than its reduction through mechanization.

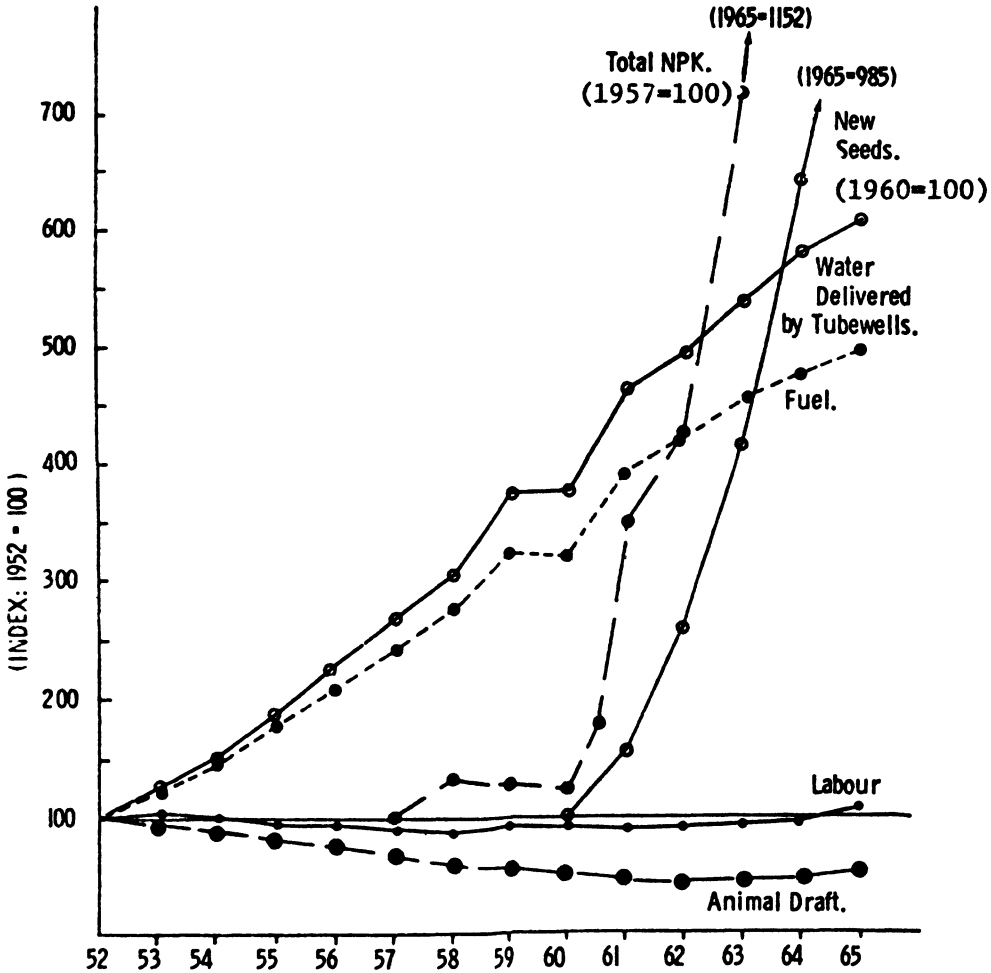

Fig. 3. Modern & Traditional Input Use in Central Punjab (1952-65)

Source: [44, Tables 3, 8, 11, 16] : MODEL RESULTS.

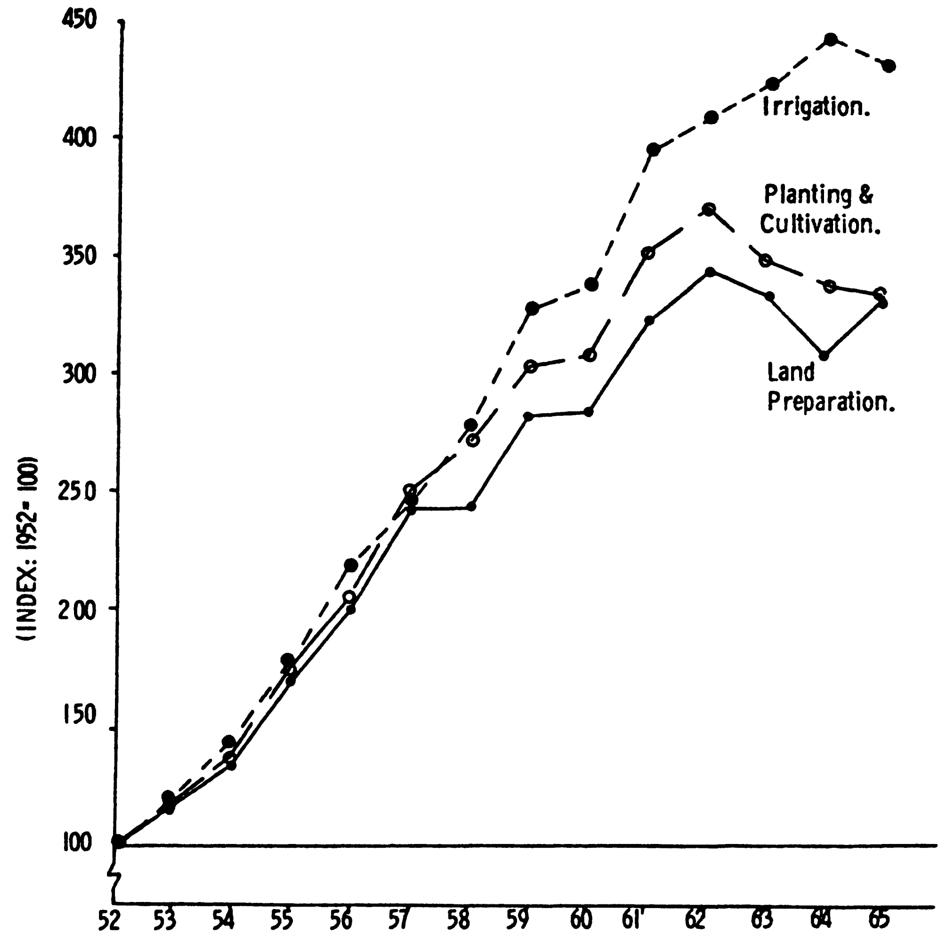

Fig. 4. Proportion of Various Tasks Performed by Mechanical Technologies in Central Punjab (1952-65).

Source: [44, Tables 5, 6, 8] : MODEL RESULTS.

After 1960 the major source of increase in land productivity involved biological innovations as shown by the indices of modern and traditional variable inputs in figure 3. The modern non-farm inputs such as new seeds and fertilizers along with fuel and tubewell delivered water increased very rapidly, while the most important traditional inputs--labour and animal draft--declined or remained relatively unchanged. These model results correctly predict the rapid adoption of the biological "green revolution" inputs as well as the changing composition of farm inputs.

The process of task specific mechanization as predicted by the model is illustrated in figure 4 which shows the increase in the proportions of irrigation planting and cultivation and land preparation that have been mechanized. Most other tasks continued to be dominated by traditional technologies, including harvesting in spite of the increase in the demand for labour during the harvesting period occasioned by increased output.

Furthermore, model predictions show that in spite of a labour surplus environment (in an aggregate annual sense) the time structure of the demand for annual labour and its changing pattern over time is such that serious seasonal scarcities and surpluses can occur. This is illustrated in figure 5 which shows seasonal labour use during the winter harvest (April 16-30) and the period just prior to it (March 16-April 15), and labour use as a percentage of available family labour, with increasing scarcity in the former and increasing surplus in the latter period.

The large changes in the composition and structure of inputs have not in general been accompanied by large changes in the composition of outputs as suggested by the fairly stable cropping pattern (figure 1).

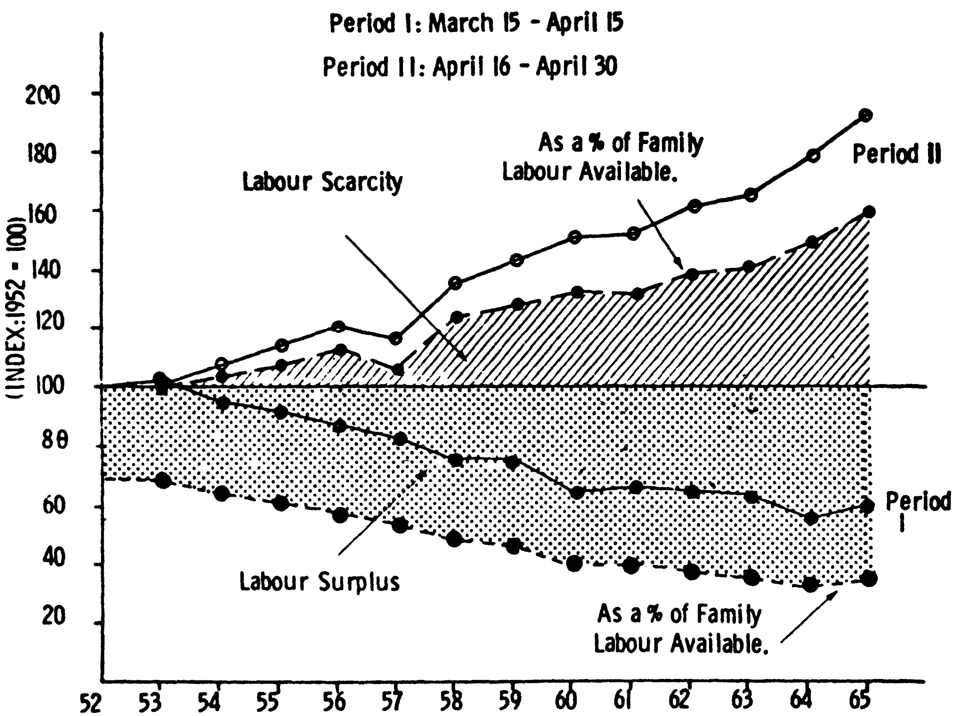

Fig. 5. Seasonal Labour Use in Central Punjab (1952-65)

Source: [44 , Tables 23,25] : MODEL RESULTS.

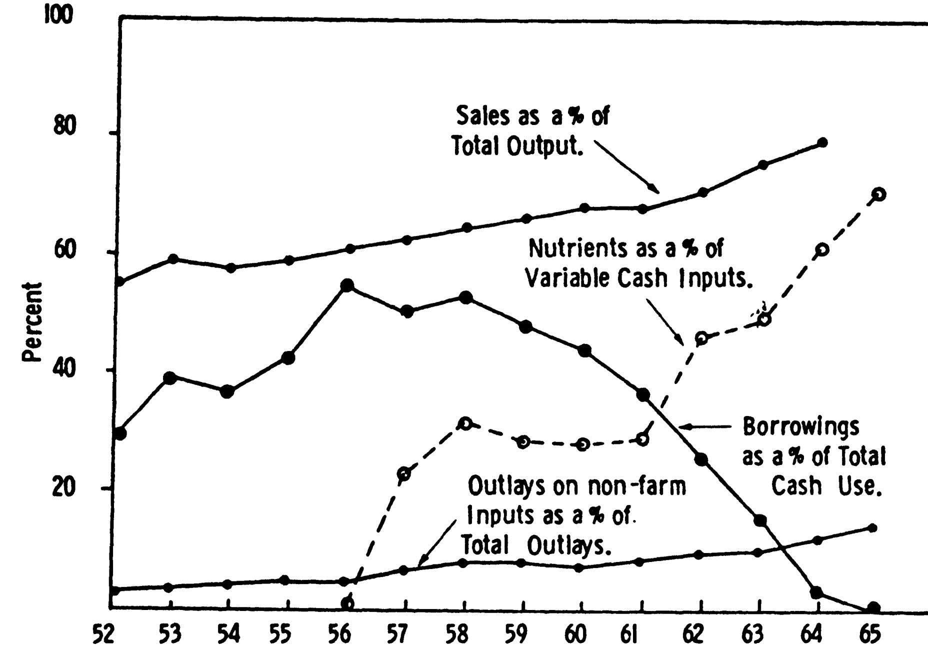

Fig. 6. Commercialization of the Farm Sector in Central Punjab (1952-65).

Source: [44, Tables 15,28,29] : MODEL RESULTS.

However, the model predicts increasing commercialization of farm production as shown in figure 6. On the output side outputs on non-farm inputs as a percentage of total production outlays have increased. A substantial part of this increase has been due to the purchase of nutrients.

An interesting reversal of this increased dependence of the farm sector predicted by the model, is the decline after 1958 in borrowings to meet cash requirements. This is due primarily to the increased output and sales that have allowed farmers to meet their debt obligations and become relatively independent of external financing. The model predicts this trend much earlier than it actually occurred, but that it did occur can be attested to by the rapid rise in rural deposits in the region after 1965.

2. Some Model Applications

The models ability to capture in a detailed quantitative manner an economic chronicle of resource use factor productivities and factor proportions is its most important although by no means only application. The large variety of model applications can be grouped into three classes i) static, ii) comparitive static and iii) dynamic.

2.1 Static Applications

The possible static applications of the model encompass all those that are possible with one period linear programming models and include a) price and cost parametrics, b) resource parametrics, and c) matrix coefficient parametrics. Thus for example, the model consisting of the l.p. problem specified by (1) and (2) for any given year 't' could be used to analyze the impact of changing the price of any given output parametrically to trace the certeris paribus supply response; or the cost of a specific input can be varied parametrically to trace the ceteris paribus derived demand for that input. Similarly varying a set of product prices relative to others traces a production frontier, while varying resource costs can allow us to trace short-term factor substitution possibilities.

Another way of tracing the demand for a resource is to vary its availability (right hand side parametrics), allowing the solutions to the dual (shadow prices) to trace its opportunity cost. Thus for example, the short-run demand for inputs such as fertilizers, water, credit, capital goods and other regional inputs can be traced by either varying their direct costs (coefficients in the objective function) or their availability to obtain a schedule of opportunity prices.

Matrix coefficient variations can also be used to trace the impact of changes in the structure of the model. A most important application here is to trace the impact of varying crop yields upon all farm activities, when yields are assumed to be known and fixed. Where crops yields have been explicitly incorporated through intermediate activities, yield variations due to weather or water utilization can be investigated. By taking a range of expected yields, a range of expected outcomes would provide a confidence interval to the model predictions that would be very useful for planning and projecting regional development.

2.2 Comparitive-Static Applications

The recursive nature of the model allows us to extend the range of static applications already discussed to a number of selected years providing a comparative-static framework. Thus for example it becomes possible not only to trace the short-run derived demand and supply response schedules, but also to approximate shifts in these schedules between any two time periods within the model. Thus shifts in the demand for inputs and the supply of outputs over time can be traced quite easily, extending considerably the range of parametric results.[28]

2.3 Dynamic Applications

Since the recursive nature of the model also allows us to capture the dynamic path of economic outcomes it's most useful applications are dynamic. Three broad sets of dynamic applications can be identified: a) simulating economic history, b) simulating policy alternatives and c) projection and forecasting.

The models ability to simulate the economic history of regional development has already been discussed. This ability allows us to obtain useful insights into the dynamics of transformation and learn how it took place, what the major constraints were during the period and what structural changes were brought about.

Alternatively, instead of using historical price and resource data and historical initial conditions, the impact of alternative policy choices or initial conditions can be simulated. Thus for example the impact of changing prices, resource availabilities and alternative technologies can be easily traced over time by changing the exogenous data or

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[28] Static and comparative-static experiments and their results for the current model are given in SINGH and DAY [45] in great detail. Also see SINGH and AHN [43] for similar applications to a r.l.p. model of the wheat region in Southern Brazil.

the behavioral parameters in the model. These dynamic simulations are particularly useful in tracing alternative historical paths to analyze, ceteris paribus, the changes in specific policies.[29]

Furthermore, by projecting exogenous data, conditional forecasts of the model can be obtained by projecting it into the future. The variety of policy issues that can be tackled and their validity will depend partly upon the reliability of the forecast on the endogenous data and partly on the ability to directly relate specific policy actions explicitly to farm payoffs and opportunities incorporated in the model.

3. Conclusions

We conclude by emphasizing the great flexibility of recursive programming models of regional agricultural development. As analytic tools they allow us to capture explicitly and often in great detail those elements that are crucial to our understanding of, and planning for modern agricultural change. Their usefulness as analytic and policy tools, however, is often limited by the availability of data in sufficient quantity and quality to allow their construction and estimation. Among the data required for a complete and detailed analysis are:

1) A detailed knowledge of mechanical technologies that provides the input structure of farm operations required to grow the major crops in the region.[30] Available farm management surveys and reports supplemented by interviews and direct observation can provide this;

[29] For a detailed excercise in dynamic simulation to analyse the impact of support price programs and subsidized credit on regional income growth and distribution using an r.l.p. framework, see AHN and SINGH [1].

[30] Such a manual for the Punjab and adjoining regions is provided in [46].

2) Time series data on input and output prices; and acreages, production and if possible investments. The prices allow the model to be estimated while observed production and investment outcomes allow its rigorous validation. These can often be compiled from regional published sources.

3) Yield-nutrient-irrigation response functions or some knowledge of the expected outcome of changes in biological technologies. These can be obtained from either experimental data, field surveys or even judgement estimates from regional experts;

4) Some data on subsistence consumption and cash expenditures by households, the most preferable (and least available) being panel data over several years. These can be obtained from sample surveys or regional published materials on farm family budgets.

Of course, one can do with less data at the expense of the richness of the model. Given these data needs it is apparent that such detailed dynamic microeconomic models have to await the development of good statistical reporting and should not be used in the first stages of analysis. However, increasingly data of good quality are becoming available in the LDCs, while the interest and growing need for sophisticated models of this nature will facilitate and can direct such data gathering activities.[31]

Additional requirements are adequate computer facilities. With recent advances in computer technologies, computation costs can be kept fairly

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[31]Adequate data for models of this nature are available in India (some states), Taiwan, Phillipines, S. Korea, Malaya, Brazil, Pakistan, Thailand, Indonesia, Nigeria, Egypt and a few more LDCs in the authors knowledge although they require gathering from a variety of sources.

low.[32] In spite of data and validation problems that often restrict their use, such dynamic models will find increasing application in the very near future.

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[32] Thus a 15 year run on the model used 1.75 minutes on the Univac 1100 System using a RDS Processor developed by DAY and associates at the University of Wisconsin.

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