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A Dynamic Multi-Commodity Model of the Agricultural Sector: A Regional Application in Brazil

A DYNAMIC MULTI-COMMODITY MODEL
OF THE AGRICULTURAL SECTOR

A Regional Application in Brazil*

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This paper develops a dynamic model to analyze the development process in the agricultural sector. Formulated as a recursive linear programming model, it contains several commodities as outputs, farm and regional resource constraints on owned and purchased inputs including working capital—and several farm sizes. The objective function is assumed to be separable for each farm size and additive for the region and measures for each year the net expected revenues from crop and livestock production less an investment charge. Prices are exogenous. The model is applied to a rapidly developing agricultural region in Southern Brazil and tested for its ability to trace regional farm sector development over a decade. It is then used to analyze the impact of alternative agricultural policies including price and credit subsidies.

1. Introduction

There is a large and growing body of literature devoted to modelling commodity decisions in the agricultural sector especially in the less developed countries (LDCs).1 The purpose of this paper is to describe one such model that is (a) dynamic, (b) based on microeconomic details of farm behavior, (c) incorporates multiple outputs and inputs, (d) includes varying farm sizes, (e) can be used extensively to analyze a variety of policy impacts,

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1See Thorbecke (1973) and Labys (1975) for brief reviews of this literature.
and (f) can be used as an analytic tool for understanding and planning regional development in the agricultural sector.

Section 2 describes the wheat producing region of Rio Grande do Sul in Brazil where the model is applied and some of the policy issues that grew out of the agricultural transformation there during the decade of the sixties. Section 3 develops the methodological framework of a dynamic model designed to examine these policy issues, and section 4 presents the model result that captures the transformation in the region and attempts to validate it. In the fifth section, we describe the applications of the model for policy analysis, and section 6 concludes with some of the advantages and limitations of this type of modeling effort.

2. Background

In recent years, there had been a single-minded emphasis on the role of new, mainly land-intensive biological technologies in transforming agriculture in the LDCs. Agricultural policies have been relegated to the role of proper supporting 'incentives' for the adoption of these 'new' technologies. This emphasis is misplaced in the Latin American context where relatively high land–man ratios prevail, and where 'new technologies' as such have played a minor role so far. In Latin America, agricultural policies in the form of price incentives to stimulate production have been at the core of development strategy.

The development of Southern Brazil, especially in the wheat-producing areas of Rio Grande do Sul, is a case in point. During the decade of the sixties, this region saw considerable growth in real agricultural output and a persistent transformation of the regional economy from range livestock production to intensive crop production. This transformation was made possible through a large program of price supports for wheat producers tied to subsidized credits available for the purchase of modern capital intensive inputs. As a consequence, total output, factor productivity and farm incomes increased substantially bringing considerable economic prosperity to the region. However, little change occurred in the biological conditions of production. Yields per hectare and per animal remained relatively stagnant throughout the decade. The distribution of farm incomes worsened while a considerable misallocation of scarce resources, especially capital resulted.

It is in this context that the role of pricing policies and their impact takes on a special significance and becomes a point of departure for the study of agricultural transformation in Southern Brazil. Government pricing policies, however, do not operate in a vacuum. Their eventual impact depends upon how they affect decision-makers on the farm and in the market. With respect to the allocation of scarce resources, decision-making at farm level becomes

\[ ^2 \text{For a detailed description of this process, see Rask (1975).} \]
the eventual filter through which both technological changes and government policy have to pass in order to have any impact. Thus, an understanding of farm-level decision-making becomes a central feature in this study.

A complication arises from the fact that farms and farmers are not homogeneous, either with regard to their relative factor endowments or in their response to economic incentives. Many of these differences are related to differences in the physical environment of production (soil, climate, topography) which are obviously critical to agricultural production. But even in a homogeneous agro-economic environment, economic response is determined by the size of the operational unit.

The importance of farm size and its relation to such factors as economies of scale, risk and uncertainty and market response has long been emphasized by many economists. Where subsistence farms exist, side by side with larger and more commercialized units, the larger farms through their greater access to technology, management and factor and product markets, usually reap a disproportionate share of the gains when transformation gets under way.

2.1. The wheat region in Rio Grande do Sul

The present study and the model structure have been tailored to the wheat-growing areas of Rio Grande do Sul in Southern Brazil. These comprise some 24 municipalities in two adjacent regions called Planalto Medio and Missoes. This agronomically homogeneous region includes some 5.7 million hectares of cultivated land—about a quarter of the total land area in the state. In 1970, the state of Rio Grande do Sul accounted for some 67 percent of the area sown to wheat, while the region of the study accounted for 42 percent of the area sown to wheat in the state. So it is fairly representative of the main wheat-growing regions of Southern Brazil. In addition to wheat, the region also accounted for about a third of the soybean area and production in Brazil. Corn production among small farmers and beef production on extensive pastures among larger farmers are also among the important agricultural enterprises in the region.

As shown in table 1, there is a wide distribution of farm size in the region resulting in substantial differences in relative resource endowments at the farm level.

Until the early sixties, most of the region was given over to large estates for the production of beef on extensive natural pastures. With the advent of special pricing and credit incentives, this region underwent a rapid transformation. These policies—which included price supports for wheat and liberalized credit—were designed to increase the production of wheat.

1 Headly (1965, ch 8) suggests that the difference in farm size is one of the most important factors explaining differences in the decision-making process of farm-firms especially in response to various economic opportunities involving risk and uncertainty.

2 Thus in 1970 the region accounted for 28 percent of the Brazilian wheat production.

3 See Rask (1975) for further evidence of these differences.
The price support program for wheat was started in 1962 with the Bank of Brazil standing ready to purchase wheat at the official support price. By 1970, this support price stood at a level nearly 80 percent above the U.S. export price. As a consequence the relative profitability of wheat increased substantially compared to traditional activities such as beef production. The ratio of wheat to beef prices in the domestic market nearly doubled between 1963–70. By way of contrast this ratio in international markets continued to decline steadily during the same period as shown in table 2. This meant an effective program of import-substitution in the production of wheat, made possible largely by wheat price supports. By 1970, the ratio of wheat to beef prices in Brazil was nearly four times larger than this ratio in international markets.

The improved profitability for wheat was accompanied by large credits, tied to the purchase of modern inputs, on very liberal terms. After 1964, modern variable inputs, such as seed, nutrients and pesticides could be purchased 100 percent on credit, at a nominal interest rate of 15 percent per annum, while farmers could obtain long-term, low-interest financing for agricultural machinery with a 25 percent down payment at a 7 percent rate of interest. Meanwhile the wholesale price index for foodstuffs increased by an average of 60 percent annually between 1960–66 and 23 percent annually between 1967–71. Thus, in effect, due to inflation, the real rate of interest on farm credits was negative during the entire decade.

This combination of policies made wheat, often double cropped with soybeans, highly profitable, and fueled a program of import substitution in wheat on a massive scale. The area under cultivation and domestic pro-

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1. *Singh and C.Y. Ahn, A dynamic multi-commodity model*

### Table 1

Farm size distribution in the wheat region of Rio Grande do Sul in 1967.

<table>
<thead>
<tr>
<th>Farm size (in hectares)</th>
<th>Number of farms</th>
<th>Percentage</th>
<th>Total land use (in hectares)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25</td>
<td>65,054</td>
<td>67.32</td>
<td>753,155</td>
<td>13.76</td>
</tr>
<tr>
<td>26-50</td>
<td>15,807</td>
<td>16.35</td>
<td>541,606</td>
<td>9.89</td>
</tr>
<tr>
<td>51-100</td>
<td>7,485</td>
<td>7.74</td>
<td>506,092</td>
<td>9.25</td>
</tr>
<tr>
<td>101-1,000</td>
<td>7,558</td>
<td>7.82</td>
<td>2,112,646</td>
<td>38.61</td>
</tr>
<tr>
<td>1,000-10,000</td>
<td>729</td>
<td>0.77</td>
<td>1,557,794</td>
<td>28.49</td>
</tr>
<tr>
<td>Total</td>
<td>96,633</td>
<td>100.00</td>
<td>5,471,283</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Table 2

Prices for wheat and beef in Brazil and in international markets (1960-70) in current Cr$/kilogram.

<table>
<thead>
<tr>
<th>Year</th>
<th>Wheat (unmilled) U.S. exports (FOB)</th>
<th>Beef (chilled &amp; frozen) Brazila exports (FOB)</th>
<th>Ratio of wheat to beef prices Domestic market</th>
<th>Exchange rate New Cr$/US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>0.0164</td>
<td>0.0127</td>
<td>0.072</td>
<td>0.0228</td>
</tr>
<tr>
<td>1961</td>
<td>0.0224</td>
<td>0.0207</td>
<td>0.104</td>
<td>0.0215</td>
</tr>
<tr>
<td>1962</td>
<td>0.04</td>
<td>0.0316</td>
<td>0.173</td>
<td>0.0231</td>
</tr>
<tr>
<td>1963</td>
<td>0.0647</td>
<td>0.0407</td>
<td>0.291</td>
<td>0.0221</td>
</tr>
<tr>
<td>1964</td>
<td>0.146</td>
<td>0.1224</td>
<td>0.533</td>
<td>0.0271</td>
</tr>
<tr>
<td>1965</td>
<td>0.206</td>
<td>0.1333</td>
<td>0.627</td>
<td>0.0329</td>
</tr>
<tr>
<td>1966</td>
<td>0.254</td>
<td>0.1378</td>
<td>0.721</td>
<td>0.0352</td>
</tr>
<tr>
<td>1967</td>
<td>0.3005</td>
<td>0.1740</td>
<td>0.815</td>
<td>0.0369</td>
</tr>
<tr>
<td>1968</td>
<td>0.3635</td>
<td>0.2358</td>
<td>0.849</td>
<td>0.0428</td>
</tr>
<tr>
<td>1969</td>
<td>0.4265</td>
<td>0.2539</td>
<td>0.993</td>
<td>0.0429</td>
</tr>
<tr>
<td>1970</td>
<td>0.49</td>
<td>0.2793</td>
<td>1.10</td>
<td>0.0445</td>
</tr>
</tbody>
</table>

cAnnuario Aro-Pecuario, 1960-70.
dU.N. Statistical Yearbook.
duction of wheat increased nearly sevenfold, while domestic production as a percentage of total domestic requirements increased from an average of 9.5 percent for the period 1962–65 to an estimated 50 percent by 1970–71. This increased program of self-sufficiency transformed the regional land use patterns from predominantly range livestock production to intensive crop production, accompanied by mechanization on medium and large farms.

3. The model

The model used in this study is similar to the regional models of agricultural development using recursive programming techniques pioneered by Day (1963a) and recently applied to agriculture in transition in the LDCs by Mudahar (1972), Day and Singh (1977), and De Haen (forthcoming). These models use a single linear programming model to represent the regional aggregate of all the production plans of farms for a given period of time. Such a regional linear program is an unbiased estimate of aggregate activity levels when certain aggregation conditions are fulfilled.\(^7\)

As the region is characterized by substantial differences in farm size and resource endowments, all farms in the region are grouped into three representative farm sizes—small farms (less than 50 hectares), medium farms (51–300 hectares) and large farms (301–10,000 hectares). It is assumed that farms within each group satisfy the required aggregation conditions and are jointly treated in a single model of the region.

The regional recursive programming model can be mathematically described as follows:

3.1. Regional objective function

The regional objective function is assumed to be separable for each farm size and additive for the region.\(^8\) It measures for each year, the net expected revenues from crop and livestock production and an investment charge for resource-augmenting on-farm activities, and is given by

\[
\text{Max } \pi(t) = \sum_q \sum_j c_j(t) x_{qj}(t),
\]

\(q = 1, \ldots, 3\) (farm size index)
\(j = 1, \ldots, n\) (activity index)
\(t = 1, \ldots, T\) (time index)

Activities distinguished by farm size include production activities (wheat,

\(^7\)For a discussion of the aggregation assumptions used in linear and recursive programming models, see Day (1963b) and Cigno (1971).

\(^8\)The assumption of separability implies that profits in one farm size group do not depend on the profits in another group, while additivity implies that both regional profits and regional resources are linear weighted sums of profits and resources in the various farm size groups.
soybeans, a soybean wheat rotation, and corn, each at two levels of
technology—traditional and modern—and beef cattle raised on either natural
or improved summer and winter pastures; purchase activities (variable cash
inputs such as hired labor, seeds, fertilizers, and livestock concentrates), sales
activities (wheat, soybeans, corn and beef), financial activities (savings,
borrowings, and debt repayment) and investment activities (the purchase of
capital goods, combines and draft animals and land improvement). Inter-
mediate transfer activities allow for the use of corn and pasture for
livestock production and the conversion of natural to improved pasture or
crop land.

The coefficient \( c_j(t) \) represents in each year the expected net return for
production activities, the cost of the variable input for purchasing activities,
the market price of farm outputs for sales activities, the nominal rate of
interest for borrowing and saving activities and an investment charge on
investment goods \( [c_j(t) = P_j(t) L_j] \) where \( P_j(t) \) is the purchase price and \( L_j \)
the use life of the investment good] for investment activities.

This objective function is maximized for each year and is subject to (a)
technical, (b) financial, (c) behavioral and (d) regional constraints which
include feedback relationships that provide the model with its dynamic
character.

(a) Technical constraints include land and labor constraints defined by

\[
\sum_j a_{q,j} x_{q,j}(t) \leq L_{q,i}(t) + H_{q,i}(t), \quad \text{for all } q. \tag{2}
\]

and quasi-fixed (machines and animal draft) capacity constraints by

\[
\sum_j a_{q,j} x_{q,j}(t) - \sum_j \delta_{q,j} x^*_j(t) \leq M_{q,i}(t). \quad \text{for all } q, \tag{3}
\]

where the \( a_{q,j} \) are IO coefficients, \( x_{q,j} \) is the \( j \)th production activity of crops
and livestock on farm size \( q \), \( L_i \) and \( M_i \) are respectively the \( i \)th land and
labor, and machine and animal draft availabilities. These constraints are
treated separately for each farm size \( q \), and are defined by type (soil and land
qualities, different machines) and by season (monthly). The on-farm availab-
ility of labor can be augmented by labor-hiring activities and land quality
can be improved by land-investment activities \( H_{q,i} \). The coefficients \( \delta_{q,i} \)
represent the additions made to the \( i \)th quasi-fixed capacity from a unit
investment in the \( j \)th investment good in the current year, and \( x^*_j \)
represents the actual investment level in the model and is endogenous.

While current investment activities add to on-farm capacities, past invest-
ments affect current capacities. These are incorporated through quasi-fixed
capacity feedback relationships by

\[ M_{qj}(t) = (1 - \lambda_{qj}) M_{qj}(t-1) + \delta_{qj} x_{qj}^*(t-1), \text{ for all } q, \]  

(3a)

where \( \lambda_{qj} \) is the annual rate of depreciation of the \( i \)th capacity, and \( \delta_{qj} \) and \( x_{qj}^* \) are as defined earlier.

(b) Financial constraints include a constraint on operating capital available on each farm size and are given by

\[ \sum_j k_{qj}(t) x_{qj}(t) - \sum_j x_{qj}^*(t) \leq W_q(t), \text{ for all } q, \] 

(4)

where \( k_j \) is the working capital requirement for each production and investment activity, \( x_{qj} \), and \( x_{qj}^* \) represents net current borrowings at various interest rates for production or investment, \( W_q \) is the operating capital available. The availability of current working capital is calculated by a financial feedback relationship from previous years gross sales and non-farm cash incomes less farm production and investment expenditures, household consumption expenditures and repayments due on borrowed capital with interest. This feedback can be written as follows:

\[ W_q(t) = \sum_j c_j(t-1) x_{qj}^*(t-1) \]  

\[ + Y_q(t-1) \]  

\[ - \sum_j k_{qj}(t-1) x_{qj}^*(t-1) \]  

\[ - \sum_j (1 + r_j) d_j x_{qj}^*(t-1) \]  

\[ - \alpha_q \left\{ \sum_j c_j(t-1) x_{qj}^*(t-1) \right\} \]  

\[ + Y_q(t-1) \] 

(4a)

where \( r_j \) is the nominal rate of interest for the \( j \)th borrowing activity, \( d_j \) is the proportion of previous accumulated borrowings that have to be paid back (\( d = 1 \) for operating capital borrowings) for each type of borrowing and \( \alpha_q \) is an exogenously estimated marginal propensity to consume out of gross returns and exogenously given non-farm cash incomes \( Y_q \), for each farm size. All \( x_{qj}^* \) represent actual activity levels in the models which are described above.
Behavioral constraints attempt to capture a variety of factors such as uncertainty, time lags in adjustment, and adoption and learning behavior that modify the response to economic opportunity at the farm-level. They incorporate adaptive, safety-first principles into microeconomic behavior that allow for protection against mistakes of cropping or investment choices and for drags on investments or new technologies due to learning and unwillingness to change.

These behavioral rules are incorporated through flexibility constraints as follows:

\[ f^l_j(t) \leq \sum_q \sum_j x_{qj}(t) \leq f^u_j(t), \]  

where \( f^l_j \) and \( f^u_j \) are respectively regional lower and upper bounds on crop production activities \( x_{qj} \) on each farm size

\[ f^u_j(t) = (1 - \gamma^u_j) \sum_q \sum_j x^*_j(t-1), \] \[ f^l_j(t) = (1 - \gamma^l_j) \sum_q \sum_j x^*_j(t-1), \]  

where \( \gamma^l \) and \( \gamma^u \) are flexibility coefficients exogenously estimated based on actually observed crop hectarages and are parameters of the model, and \( x^*_j \) are actual (predicted) crop hectarages in the model.\(^9\)

Maximum potential investment bounds are defined for investment activities by

\[ \sum_q x_{qj} \leq m_j(t). \]  

Here \( x_{qj} \) is investment by farm size group \( q \) in the \( j \)th capacity and \( m_j(t) \) the limit in the year \( (t) \) on this investment determined by the 'adjustment rule',

\[ m_j(t) = \rho_j[M_j - \sum_q M_{qj}(t-1)], \]  

where \( M_j \) is the long-run desired capacity for the given capital good in the region and \( M_{qj}(t) \) is the initial capacity in farm group \( q \) of the given capital good as determined by (3) and \( \rho_j \) is the 'adjustment coefficient', a parameter in the model.\(^{10}\)

A final set of adoption constraints reflect friction in adopting new

\(^1\) For an early use of flexibility constraints in agricultural models, see Henderson (1959). And for their use in recursive programming models, see Day (1963a) and Day and Singh (1977), and for a discussion of various estimation procedures that can be used, see Miller (1972).

\(^9\) The 'desired level' is measured by the maximum level of new technology possible assuming no supply constraints on its availability.
technologies throughout the region and are given by bounds on the use of modern technologies applied to individual commodities or livestock activities. Let \( x^*_j \) be the subset of new production activities that involve the use of ‘new’ machines and practices. Then the adoption constraints are

\[
x^*_j(t) \leq e_j(t),
\]

where the limitation coefficients \( e_j(t) \) are generated recursively by

\[
e_j(t) = (1 + \beta_j)x^*_j(t - 1),
\]

and \( \beta_j \) is the ‘adoption coefficient’ which defines the maximum rate at which new technologies can grow in view of biological or supply considerations exogenous to the farm.\(^\text{11}\)

\( (d) \) Regional coupling constraints restrict the use of hired labor and credits on farms of all sizes by the regional availability of wage labor (by season) and the total supply of bank credit. Regional wage labor constraints are given by

\[
\sum_q H_{qi}(t) \leq \bar{H}_i(t),
\]

where \( H_{qi} \) is the activity associated with the hiring of labor on farm size \( q \) in season \( i \) and \( \bar{H}_i \) is the seasonal availability of wage labor in the region.

The supply of credit is assumed to be limited to the region as a whole but allocated efficiently among farm groups within the region. Then we have regional credit constraints given by

\[
\sum_q \sum_j x^1_{qj} \leq w \cdot \sum_q \sum_j C_j(t - 1) x^*_j(t - 1),
\]

where \( x^1_{qj} \) are the borrowing activities and \( w \) is the ‘borrowing coefficient’ used as a rule of thumb by credit institutions in extending credit, and \( x^*_j \) is the \( j \)th sales activity \( C_j \) the market price of farm outputs sold. Thus the sum of regional borrowings in the current period are not allowed to exceed a fraction of previous years gross revenues for each farm size in the region.\(^\text{12}\)

\( ^\text{11} \)The adoption and adjustment coefficients and the constraints associated with them define the familiar ‘S’-shaped path over time for investments in capital goods involving two phases called the adjustment and adoption phases. These phases are also evident in investment behavior in the industrial sectors. These phases have been analyzed and empirically verified by Day et al. (1970).

\( ^\text{12} \)The ‘rule of thumb’ used by credit institutions is that their total lending to any farmer is not allowed to exceed in value 60 percent of his expected gross revenues from farm operations. Thus \( w = 0.6 \) in the model. See Engler (1971) and Ahn (1972) for a discussion of the relevance of this rule in the region.
The endogenous variables in the model include for each farm size, the production of crops and livestock (by technology - traditional and modern); investment levels in farm power (tractors, harvesters and draft animals); working capital expenditures on machines, fertilizers, seeds, bone meal, concentrates and fuel; borrowings and savings levels and labor utilization by family and wage labor categories, by individual activity, by season and by crop. The exogenous variables include market prices, interest rates, supplies of land and family labor by farm size, wage labor in the region and non-farm incomes by farm size. The parameters of the model include input output coefficients for each technology, flexibility, adjustment, adoption and borrowing coefficients and the average propensity to consume out of gross sales by farm size, and depreciation rates on machine capacities.

The model is estimated by setting up and solving a linear programming problem for a given initial year - 1960 in this case. A new set of limitation and constraint coefficients is then computed by substituting the optimal solution vector just obtained and exogenous data or trends into the feedback functions. A new objective function using exogenous input and output price data is obtained and a new linear programming problem solved. This method generates a sequence of recursive programs with model outcomes for each year.

Detailed data on physical input output coefficients were constructed from a random sample of some 430 crop and livestock farms in the region of study supplemented by information obtained from field surveys. The sample also provided data for on-farm resources by farm size which was supplemented by data on regional resources from the Brazilian census, and other published sources.13

4. Model validation and results (1960-70)

Before going into detailed model results, we wish to provide an evaluation of the model. This is done by comparing the predicted model outcomes with observed outcomes for the period 1960-70 and the results are available in Ahn (1972). In spite of serious difficulties, methodological and practical, in arriving at proper evaluation criteria, several methods have been developed to evaluate such models.14 However, in this study the extreme paucity of regional and subregional data prevents a rigorous statistical evaluation.

The model predicts the wheat hectarage fairly closely with slight overpredictions for the years 1964, 1965, and 1966 and small underpredictions for the years for which data are available. In addition, the model does fairly well in predicting wheat hectarage by technology.

13 The initial conditions, input requirements for each activity, exogenous input and output prices and other data sources used are given in Ahn (1972).

14 See Day and Singh (1977) for several evaluation techniques that can be used and their limitations.
While further statistical tests are not possible the model does provide a detailed, quantitative chronicle as it were, of both the input and land use structure underlying the transformation that took place during the decade. These predictions can also be used to validate the soundness of the model and its structure.

4.1. Land use and cropping patterns

The most important changes that took place in the region have involved a transition from extensive livestock production using natural open range pastures to intensive crop and livestock production. This is correctly captured by the model in the predicted land use patterns.

The model shows approximately a million hectares of open range land—a quarter of the total—being converted to intensive crop and livestock production. Crop land is shown to have increased fourfold mainly through double cropping; areas devoted to wheat, soybean and beef production on improved pastures have increased enormously (most dramatically on large farms, least on small farms); corn production (mainly a subsistence crop) is shown to have remained fairly stable (increases on small farms offset the decreases on medium and large farms). In short, the model predicted that the open range, with beef production on extensive pasture lands and all the popular and memorable images associated with the gaucho and his way of life in Latin America, were on their way out, to be replaced by intensive and mechanized crop farms mixed with intensive beef production systems. These results can be readily verified from direct observation as well as regional statistics.

4.2. Farm technology, capital utilization and employment

Further evidence of the model's ability is provided by its predictions relating to the detailed economic structure of production and technology as seen in fig. 1.

Although farms of different size follow similar trends in their cropping patterns, their predicted choice of technologies reveal striking differences. Small farms with relatively abundant labor employ only traditional draft animal technologies. On the other hand, large farms with relatively scarce labor utilize exclusively modern tractor-combine technologies. Between these two extremes, the medium-sized farms show a mixed pattern, but inclined towards the labor-saving modern technologies. The predicted increase in the use of modern farm power is dramatic—a 3.5 and 4.2 fold increase in tractor use and a 10.3 and 7.1 fold increase of combine use (not shown in figure) on medium and large farms respectively.

Again, these rapid trends in mechanization especially in medium and large farms and the almost exclusive reliance on traditional draft animal technologies on small farms in the region predicted by the model can be amply supported by both observation and other independent studies of the region.
Fig. 1. Farm technology, capital utilization and employment. (Source: Model results).
Although the model provides estimates of only on-farm investments and capital use, the predicted growth in these categories has been impressive. Investments in tractors grew by 320 percent on large and 200 percent on medium farms; while similar trends are observed for combines. As a result the value of on-farm quasi-fixed capital stock—that is, the stock of machinery and draft animals used for farm power, less depreciation—increased ninefold at constant 1970 prices during the decade.

Equally impressive has been the growth in the use of operating capital. Using a weighted index of all inputs at constant 1970 prices,\(^{15}\) total cash outlays on small, medium, and large farms increased significantly by 178, 183, and 211 percent, respectively, during the decade of the sixties. This has been the direct result of a transition from extensive livestock operations requiring little operating capital to intensive crop and livestock operations requiring large amounts of operating capital for fuel, hired labor, repairs, pesticides and nutrients. Nearly two-fifths of the predicted increase in operating capital was due to an increased outlay on nutrients.\(^{16}\)

In spite of the limited scope of the investment activities modelled, there are important reasons for highlighting the predicted gross investments in farm machinery. First, they accounted for most of the gross capital investments, especially on larger farms. Second, most of the credits advanced for investments were applied to the purchase of farm machinery.

These predicted increases in gross investments in capital stock of quasi-fixed capacities predicted by the model—confined mainly to the purchase of draft animals, tractors, combines and ancilliary equipment—are supported by other studies also.\(^{17}\) On a per hectare basis the model predicted higher capital use on larger farms and a higher labor use on smaller farms as would be expected.

The predicted trends in farm employment reflect the differences in relative factor scarcities, cropping patterns and the choice of technologies that prevailed. Three salient features of the predictions stand out. First, total employment increased mainly on small farms where it is most desirable—more than tripling. Small farms accounted for more than 90 percent of the increase in total employment in the region. Second, large farms accounted for most (the model predicted all) of the hired labor employment in the region, as expected. These broad results stand to reason and have also been substantiated in other studies.\(^{18}\)

In addition the model predicted the following trends that were sub-

\(^{15}\)That is weighted by the predicted amount of each input used each year.
\(^{16}\)Since no nutrients are used on open range pasture, a mere shift to intensive crop farming involving small amounts of nutrient use per hectare has meant a large increase in total outlays on nutrients. Nutrient use per hectare and nutrient yield responses have, however, remained extremely low.
\(^{17}\)Particularly see Rask (1975) and Sanders (1973).
\(^{18}\)See Rask (1975) and Glover (1975).
stantiated both through direct observations and by other studies:

(i) an increase in the use and reliance on credit as a means of financing on-farm production and investment expenditure, especially on large and medium farms:

(ii) an increase in land and labor productivity on all farms especially after 1964;

(iii) an inverse relationship between average and marginal returns to capital expenditures and farm size; and

(iv) a growing inequality in farm incomes especially between small and large farms particularly when net returns to family labor was used as the income measure.

The availability of better and more detailed data by farm size on farm production, and resource use could have enabled the model to be 'validated' more properly in a quantitative sense. We feel, however, that the model's ability to capture the main structural changes in detail over a decade, provides us with enough confidence to proceed to use it for policy analysis and experiment.

5. Model applications for policy analysis

As recursive programming models of the type used in this study are both structurally rich and dynamic in nature, they are capable of being applied in a variety of ways. By changing the price of any given commodity parametrically the short-run supply response can be traced. An excellent example of the use of this kind of analysis to look at policy issues with l.p. models is provided by Duloy and Norton (1975). This is now a fairly widely used tool for obtaining estimates of direct cross-price arc elasticities for agricultural products under varying conditions of technology, price controls and even tenure.

What is less widely used is the variation in the cost of specific inputs (labor, nutrients, credit) to trace the short-run derived demand for regional or farm-specific inputs. Examples of this type of parametric analysis are provided in fig. 2, where, by varying the nominal rate of interest on short-term borrowing the derived demand for credit is traced by farm size for three benchmark years.

The importance of credits as a source for financing farm expenditures (see table 3) is best viewed in the context of the rates of inflation that prevailed during the decade. For example, the wholesale agricultural price index increased by 36 percent, 47 percent and 27 percent, respectively, between 1960-61, 1964-65 and 1970-71, the three benchmark years we focus on. During this same time working capital could be obtained on credit at a nominal 10 percent rate of interest. The question that is of obvious interest is whether the demand for credit would have been similar if ‘realistic’ real rates
Table 3

<table>
<thead>
<tr>
<th>Items</th>
<th>1960</th>
<th>1965</th>
<th>1970</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Gross value of output (in 1,000 Cr.$ at 1960 prices)</td>
<td>SF</td>
<td>6,021.6</td>
<td>7,143.2</td>
</tr>
<tr>
<td></td>
<td>MF</td>
<td>500.8</td>
<td>9,243.7</td>
</tr>
<tr>
<td></td>
<td>LF</td>
<td>11,333.4</td>
<td>12,714.3</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>25,855.4</td>
<td>29,121.2</td>
</tr>
<tr>
<td>B. Resource use</td>
<td>SF</td>
<td>106.00</td>
<td>172.77</td>
</tr>
<tr>
<td>1. Area cropped: (1,000 hectares)</td>
<td>MF</td>
<td>125.50</td>
<td>134.23</td>
</tr>
<tr>
<td></td>
<td>LF</td>
<td>170.00</td>
<td>178.51</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>401.50</td>
<td>485.61</td>
</tr>
<tr>
<td>2. Area sown to wheat: (1,000 hectares)</td>
<td>SF</td>
<td>20.00</td>
<td>74.26</td>
</tr>
<tr>
<td></td>
<td>MF</td>
<td>29.50</td>
<td>41.89</td>
</tr>
<tr>
<td></td>
<td>LF</td>
<td>40.00</td>
<td>58.00</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>89.50</td>
<td>174.15</td>
</tr>
<tr>
<td>3. Annual labor use: (million man hours)</td>
<td>SF</td>
<td>56.763</td>
<td>65.419</td>
</tr>
<tr>
<td></td>
<td>MF</td>
<td>28.890</td>
<td>31.996</td>
</tr>
<tr>
<td></td>
<td>LF</td>
<td>15.348</td>
<td>14.905</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>101.091</td>
<td>112.320</td>
</tr>
<tr>
<td>4. Annual machine use: (tractors and combines in million B.H.P.)</td>
<td>SF</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>MF</td>
<td>37.075</td>
<td>49.307</td>
</tr>
<tr>
<td></td>
<td>LF</td>
<td>65.870</td>
<td>82.290</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>102.945</td>
<td>137.597</td>
</tr>
<tr>
<td>5. Annual draft animal use: (in million hectares)</td>
<td>SF</td>
<td>795.56</td>
<td>1,266.37</td>
</tr>
<tr>
<td></td>
<td>MF</td>
<td>242.96</td>
<td>288.81</td>
</tr>
<tr>
<td></td>
<td>LF</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1,038.62</td>
<td>1,555.81</td>
</tr>
</tbody>
</table>
6. Total capital outlays:
   (in 1,000 Cr.$ at 1960 prices)
   \[
   \begin{array}{ccc}
   & SF & MF & LF \\
   Total & 1,015.23 & 1,763.69 & 2,998.82 \\
   & 1,352.89 & 1,733.26 & 2,884.52 \\
   & 2,362.45 & 3,043.06 & 6,364.38 \\
   & 5,777.74 & 5,970.67 & 11,769.89 \\
   \end{array}
   \]

7. Borrowing as a percentage of capital outlays:
   (in 1,000 Cr.$ at 1960 prices)
   \[
   \begin{array}{ccc}
   & SF & MF & LF \\
   Total & 35.3 & 42.6 & 47.8 \\
   & 26.8 & 18.5 & 54.1 \\
   & 32.9 & 72.9 & 100.0 \\
   \end{array}
   \]

C. Average factor productivities
   (at constant 1960 prices)
   1. Labor (Cr.$/hour):
      \[
      \begin{array}{ccc}
      & SF & MF & LF \\
      Total & 0.106 & 0.293 & 0.738 \\
      & 0.109 & 0.289 & 0.853 \\
      & 0.107 & 0.328 & 1.101 \\
      & 0.256 & 0.259 & 0.285 \\
      \end{array}
      \]

2. Land (Cr.$/hectare):
   \[
   \begin{array}{ccc}
   & SF & MF & LF \\
   Total & 5.64 & 5.66 & 5.69 \\
   & 6.55 & 6.12 & 6.33 \\
   & 8.29 & 7.44 & 9.18 \\
   & 5.67 & 6.31 & 8.40 \\
   \end{array}
   \]

3. Capital (Cr.$/Cr.$):
   (net revenue/total outlays)
   \[
   \begin{array}{ccc}
   & SF & MF & LF \\
   Total & 4.93 & 3.82 & 2.78 \\
   & 4.28 & 4.34 & 3.41 \\
   & 2.99 & 2.81 & 1.99 \\
   & 3.48 & 3.88 & 2.40 \\
   \end{array}
   \]

D. Factor proportions
   (inputs per hectare)
   1. Labor (hours):
      \[
      \begin{array}{ccc}
      & SF & MF & LF \\
      Total & 53.14 & 19.30 & 7.71 \\
      & 59.97 & 21.14 & 7.42 \\
      & 77.30 & 22.65 & 8.33 \\
      & 22.17 & 24.35 & 29.42 \\
      \end{array}
      \]

2. Working capital:
   (constant 1960 Cr.$)
   \[
   \begin{array}{ccc}
   & SF & MF & LF \\
   Total & 0.95 & 1.00 & 1.13 \\
   & 1.22 & 1.11 & 1.27 \\
   & 2.04 & 1.61 & 2.49 \\
   & 1.04 & 1.20 & 2.10 \\
   \end{array}
   \]

\textsuperscript{a}SF: small farms, MF: medium farms, LF: large farms.
of interest had been charged to the farmers during these years. The parametric results obtained by varying the interest rate on borrowed capital (the objective function coefficient associated with the short-term borrowing activity) are revealing.

They show that if a real rate of 10 percent per annum had been charged i.e., nominal rates of 46, 57 and 37 percent for the benchmark years - short-term total borrowings would have declined by 65 and 45 percent, respectively, in 1960 and 1970 and would have dropped to zero in 1965! Further, they show that although large farms account by and large for most
of the borrowing, their demand for debt is most elastic, so elastic that if positive rates of interest had been charged, say in 1965 or 1970, there would have been little or no borrowing by them for farm production. Indeed we were able to show that over 30 percent of the debt on medium farms and over 65 percent on large farms was due to low (negative real) rates of interest being extended at levels not at all justified by the productivity of capital on these farms. This is a clear case of how factor-price distortions (in favor of capital in this case) can seriously alter resource use patterns and affect their efficient use at the farm level.

As descriptive tools, all programming models provide detailed estimates on such variables as output levels (gross or net), resource use (slack, and binding resources by activity and season), factor productivities (average and marginal), and factor proportions (resource use ratios) for whatever criterion function one has maximized.

The recursive nature of the model allows us to extend the range of such static applications to a number of selected years providing a comparative-static framework. Table 3 provides a sampling of the type of descriptive information that can be obtained from the present model. These results need to be distinguished from the results one would obtain from static I.P. models estimated with exogenous price and resource constraints for these years separately, because in the I.P. framework many on-farm quasi-fixed and capital constraints are estimated endogenously and depend upon previous decisions being generated by the model.

Further it becomes possible to trace not only the short-run derived demand and supply schedules but also shifts in these schedules between any two time periods. In this manner longer-run shifts in the demand for inputs and supply for outputs over time can be traced, and movements along isoquants can be distinguished from movements along expansion paths, when the value of output is held constant.

Examples of this type of application are shown in fig. 3, where short-run substitution possibilities between labor- and machine-intensive technologies and the marginal efficiency of capital schedules as well as longer-run shifts in these schedules between benchmark years are plotted. (The arrows show the 'initial' solution in each year.) Fig. 3b shows that the short-run elasticities of substitution between labor and machine use were relatively high in the region so that changes in relative factor prices and/or relative seasonal factor scarcities in the direction of more scarce capital would have resulted in labor being substituted quickly for machine use.

Fig. 3a shows a substantial shift in the derived demand for capital over time and an increase in its elasticity. The rates of return at the initial margin are relatively low, ranging between 10-30 percent nominally and are generally below the inflation rate in these years suggesting that the real rates

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19 See Singh and Ahn (1975).
of return to capital at the farm level were negative. Reduced credits would have made capital more scarce, increased its on-farm rate of return and allowed it to be used more efficiently.

In the context of our study, we can further use the model to analyze the significant impact of wheat support programs accompanied by credit subsidies. These impacts can best be revealed by asking what might have happened in terms of regional development if these policy instruments had not been used as they were.

Fig. 4 provides some selected results from these counterfactual exercises when the model is used to simulate three policy options: (i) a policy of wheat price supports for wheat accompanied by liberal credit terms that actually prevailed in the region in the sixties, (ii) an alternative that would have allowed the wheat price supports to remain but would have encouraged banks to charge positive real rates of interest on agricultural loans (i.e., over and above the inflation rate) thus preventing the enormous implicit credit subsidies that actually prevailed, and (iii) an alternative that would have dropped both price supports and the implicit credit subsidy, and brought the
The results from these three policy options are labeled P(1), P(2) and P(3). Policy option P(2) is designed to evaluate the impact of the implicit credit subsidies and P(3) to evaluate the joint impact of both price support programs and a policy of liberal credits.

The results clearly show that the wheat price supports accompanied by an implicit subsidy on credits led (i) to substantial growth in regional output mainly through increased area devoted to wheat (and soybeans) on all farms and (ii) to increased capital and credit use and overcapitalization (including mechanization). We were further able to show that although farm income differentials increased, these were mainly due to differences in the initial and cumulative resource endowments and not policy changes. Further, we used the counterfactual results to show that although the program of self-sufficiency through import-substitution was most successful in Brazil it was achieved at a fairly high net social cost.

Finally, by projecting exogenous data on input and output prices and regional land and labor supplies, conditional forecasts of the model can be
Fig. 4. Simulation of alternative policy options (counterfactual simulation).
obtained. Although again a variety of policy issues can be tackled, we found that the validity of the forecasts rests critically on the reliability of the price forecasts used. We have reported these results elsewhere [see Ahn and Singh (forthcoming)]. Given the volatility experienced in international agricultural commodity markets in the period 1971-76 it is doubtful that even the most sophisticated price forecasting techniques would have been accurate enough to allow us to obtain better model predictions.

6. Conclusions

We have shown how dynamic multi-crop programming models can be used for economic and policy analysis in the agricultural sector. It is appropriate to conclude by summarizing what these models are or are not capable of doing, and their advantages and limitations.

The advantages these models offer are several. First, by taking a micro-economic focus they are useful tools for looking at the farm level impact of various policy options in a detailed and quantitative way. Where concerns are focused on what is likely to happen to resource use and efficiency and output patterns within the agricultural sector as a result of policy actions aimed specifically at this sector they are most useful.

Second, as they incorporate the competition of multiple outputs using common resources, they are most useful where agriculture is characterized by a number of commodities grown by a large number of producers with great differences in their resource endowments.

Third, by taking account of technology alternatives in great detail they are capable of tracing through the consequences of specific technology choices at the farm level and are likely to be most useful where new biological or mechanical technologies are bringing about rapid change in the sector.

Fourth, they are useful as tools for understanding, projecting and planning the dynamic consequences of alternative policy options at the farm level. In this regard they can be used for analyzing a variety of policy issues relating to technologies, input and output prices and resource controls.

Last, as they are able to treat the heterogeneous farm level characteristics including size, they are able to trace the distributive impacts of policy options in the agricultural sector, an area of growing interest in development policy.

These models on the other hand, also have severe limitations in terms of what they are not able to do that also need to be emphasized. First, as they take commodity and input prices as exogenous they are not able to predict them either in a forecasting or normative sense. There are programming models of the agricultural sector that are designed to do this, but the present model is not among them.20

20See for example Duloy and Norton (1973), Kutecher and Scandizzo (1976).
Second, although less partial than some, the models are still partial and totally open— that is, they assume that infinite demand elasticities for farm outputs and supply elasticities for non-farm inputs face farm-level decision-makers. These assumptions are valid only if the aggregate region modelled is small enough so that its decisions do not affect prices in the domestic market. These assumptions are generally not tenable. However, programming models can be extended to incorporate more realistic assumptions on price elasticities although this particular model does not incorporate them.

Third, pertaining to a given region characterized by particular production opportunities, they do not relate to the entire agricultural sector, but only to a given region in it. All these limitations are not limitations of the methodology as such but this particular application. These can be overcome by incorporating more regions and demand and supply constraints for outputs and inputs, but with the added cost of increasing the size of the problem enormously.

Fourth, they do not link to other sectors except indirectly. The derived demand for inputs by the farm sector and its supply of outputs are not related to the supply of inputs or the demand for farm outputs from other sectors: non-farm and foreign. Thus intersectoral impacts and the foreign trade sector are not treated explicitly and policy issues relating to them would require additional work exogenous to these models. They cannot be used to look at commodity import or export problems except to the extent that they provide detailed information on the domestic production side.

Last, several methodological points relating to the particular way in which behavioral constraints have been used to model farmers’ response to such factors as uncertainty and learning behavior remain in contention, so that a certain amount of healthy scepticism should be retained in the use of these models.

In spite of these shortcomings dynamic models to analyze the multi-commodity environment in the agricultural sector can provide useful analytical and policy insights into the regional development process. As such they will be increasingly used where data are available. Their use in LDCs at present is limited more by the paucity and quality of the data required to estimate them, than by either their cost or methodological complexity.

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