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SPATIAL PROGRAMMING OF PRODUCTION FOR AGRICULTURAL DEVELOPMENT IN INDIA*

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Numerous policy measures have been used to promote economic development of agriculture in India and to meet targets of agricultural production. The important policy instruments, used for the First, Second and Third Five-Year Plans, include greater fertilizer application, irrigation development, land reclamation, soil conservation, community development, extension education and land reform and planning itself. The planning activity, while based on estimates of potentials by regions, has been based on less formal methods. In this study, we apply a formal programming model to consider inter-regional interdependencies of agricultural production. The model formulated, using up to 467 equations and variables, considers regional land constraints, the comparative advantage of different regions for various crops and an array of restraints. The objective of the study is to examine the extent to which the efficiency in agricultural production and land utilization might be improved through the use of programming models which allow consideration of interdependencies of regions and specified policy restraints. Hence, we compute optimum land use plans and compare these with the production allocation at the end of the Second Plan.

THE MODEL

An inter-regional programming model is employed to determine the optimum allocation of acreage among competing crops and regions of India. The model assumes the region to be a producing unit. The objective function specifies the maximization of the value of production from the crop sector subject to the following restrictions:

1. The acreage under each crop is allowed to vary within specified limits for each region. However, these limits do not allow acreage of a crop currently grown in a region to drop to zero. Effectively, minimum restraints are used in order that adjustments do not exceed the ability of regions to accommodate them. Maximum restraints serve similarly and also prevent crop acreages which exceed conservation requirements. In considering acreage adjustments, we use three limits by which acreage of any crop may change in each region. For all crops but sugarcane, we allow changes of $\pm$ 10 per cent, $\pm$ 20 per cent and $\pm$ 40 per cent of the existing acreage. We use three different levels of change to examine the extent of improved efficiency in the crop sector, if institutional or policy considerations allowed changes of these magnitudes. In other words, we compute separate solutions for our model when restraints are changed to allow changes of these three magnitudes. The percentage change allowed for sugarcane is $\pm$ 5 per cent, $\pm$ 10 per cent and $\pm$ 20 per cent—since sugarcane is a year round crop, while the others are seasonal. The levels of changes in acreages allowed in the study give it the characteristics of comparative statics types of models.

* This paper may be viewed as an exercise in the application of parametric programming for agricultural development in India. Its immediate value as a guide to Indian policy is limited by lack of availability of appropriate data. (Ed.)

In view of the planned efforts for agricultural development in India, these limits are considered and no attempt to project the past trends is made.

2. A total acreage restraint is used for each region. Changes in the acreage of individual crops must conform to this overall regional restraint. Generally, land area is already fully cropped and little additional land can be brought under cultivation. Whenever reclamation or improvement allows this shift, however, restrictions can be changed accordingly.

3. Incomes from crop production in the various regions are not allowed to drop below minimum levels based on a specified base period. Augmented value of production in the crop sector cannot be attained through reduction of income in a particular region. We impose this restriction in order that producers in no region are made "worse off" in terms of income so that better or positive sum outcome is guaranteed. Hence, within the realm of the economic sector considered, we do not allow an increased aggregate value of product to cause decreased income in individual regions.

4. The production levels attained at the end of the Second Five-Year Plan are specified as a set of minimum restraints in the programming model. These restrictions, termed availability restraints, also allow us to test the validity of existing price relationships among different commodity groups. These tests are discussed in a later section dealing with the dual of our model.

The mathematical structure of our model is summarized as follows. The primal solution is:

$$(1) \quad \text{Max}: \sum_{k=1}^{U} \sum_{j=1}^{P} C_j^L X_j^L$$

where $U = 17$ regions, $P = 16$ crops, X_j^L is the level of the j-th activity in L-th region (an activity unit is taken as one acre of a crop) and C_j^L is the income per acre from the j-th crop in the L-th region subject to :

$$(2) \quad X_j^L \geqslant A_{j(min)}^L$$

$$(3) \quad X_j^L \geqslant A_{j(max)}^L$$

$$(4) \quad \sum_{j=1}^{P} X_j^L = A^L$$

$$(5) \quad \sum_{j=1}^{P} C_j^L X_j^L \geqslant I^L$$

$$(6) \quad \sum_{L=1}^{U} \sum_{j=1}^{8} Y_{j(f)}^L X_{j(f)}^L \geqslant F$$

$$(7) \quad \sum_{L=1}^{U} Y_{j(s)}^L X_{j(s)}^L \geqslant S$$

$$(8) \quad \sum_{L=1}^{U} Y_{j(c)}^L X_{j(c)}^L \geqslant C$$

$$(9) \quad \sum_{L=1}^{U} Y_{j(g)}^L X_{j(g)}^L \geqslant G$$

$$(10) \quad \sum_{L=1}^{U} \sum_{j=12}^{16} Y_{j(o)}^L X_{j(o)}^L \geqslant 0$$

$$(11) \quad X_j^L \geqslant 0$$

A^L, the cropped area for region L, is available to all crops in that region. $A_{j(min)}^L$ and $A_{j(max)}^L$ respectively are the minimum and maximum level of acreages for the j-th crop in the L-th region. Y_j^L represents the yield per acre of the j-th crop in the L-th region. F, S, C, G, and O are the minimum quantities of foodgrains, sugarcane, cotton, jute and oil seeds specified at the national level. I^L indicates the minimum income level for the L-th region below which income of that region is not allowed to decline. Manual labour and bullock labour, chief sources of power on farms, are not included in the system of restrictions because of their large scale under-employment and unemployment (reported by a number of studies). The dual solution is :

$$(12) \quad \text{Minimize}: \sum_{L=1}^{U} \gamma^L A^L - \sum_{L=1}^{U} \sum_{j=1}^{P} \gamma^L_{j(min)} A^L_{j(min)} + \sum_{L=1}^{U} \sum_{j=1}^{P} \gamma^L_{j(max)} A^L_{j(max)} - \sum_{L=1}^{U} \delta^L I^L - P_f F - P_s S - P_c C - P_g G - P_o O$$

subject to

$$(13) \quad \gamma^L - \gamma^L_{j(min)} + \gamma^L_{j(max)} - \delta^L C^L_j - P_f Y^L_{j(f)} - P_s Y^L_{j(s)} - P_c Y^L_{j(c)} - P_g Y^L_{j(g)} - P_o Y^L_{j(o)} \geqslant C^L_j$$

$$(14) \quad \gamma^L, \gamma^L_{j(min)}, \gamma^L_{j(max)}, \delta^L, P_f, P_s, P_c, P_g \text{ and } P_o \geqslant 0$$

In the dual, γ^L is the general gross rent per acre of land in the L-th region. $\gamma^L_{j(min)}$ is the specific rent for the j-th crop in the L-th region if the minimum acreage limit for that crop is binding. Similarly, $\gamma^L_{j(max)}$ is the specific rent for crop j if the upper acreage limit for a crop is effective. δ^L is the proportion by which income in the L-th region should be raised to meet the minimum income requirement of the region. This minimum income might be attained through programmes of subsidies : P_f, P_s, P_c, P_g and P_o are the subsidy prices for foodgrains, sugarcane, cotton, jute and oil seeds respectively which must be added to the respective regional prices to induce regions to produce the commodities at their minimum levels. The magnitudes of P_f, P_s, P_c, P_g and P_o will be greater than zero only if constraints 6, 7, 8, 9 and 10 respectively, are binding. In case these values exceed zero, existing price relations among commodities are not consistent with the composition of the agricultural production sought. These subsidy prices would provide the adjustment factors to bring the prices in line with the objectives of the policy.

C^L_j, income per acre of the j-th crop in the L-th region, needs further explanation. It has been estimated by multiplying the yield per acre of a crop by the corresponding regional price per unit of the main produce of a crop. Net income might have been employed for C^L_j. However, capital costs represent a minor proportion of the inputs for crops and farm production in the country. Hence, regardless of whether the C^L_j are based on either value of the main produce or on net income, the resulting programmed cropping plans will be highly similar, if not identical.† This would be less true had we considered large new capital outlays for improvements in technologies and addition of resources.

The primal has 214 activities and 467 restraints of types 2 to 10 above. The reverse is true for the dual, which has 467 variables and 214 equations. The solutions for several levels of adjustment considered (*e.g.*, ± 10 per cent, ± 20 per cent, ± 40 per cent) are obtained through parametric programming methods.

† What matters is not that the proportion of capital to total cost is small but its likely variation from region to region and crop to crop. (Ed.)

BASE PERIOD AND COVERAGE

The base period for acreage restraints and average commodity prices for each region is 1956-57 to 1960-61, the period covered by the Second Five-Year Plan. Production coefficients Y_j^L are based on data for 1960-61. The reason for selecting this particular year for production coefficients is to take into account technological improvements brought about during the Second Five-Year Plan. Furthermore, 1960-61 is the base year for the Third Five-Year Plan and is considered to be broadly, a normal year.

India is divided into 17 regions covering 99.8 per cent of the nation's total cropped area. Sixteen crops including eight foodgrains (rice, jowar, bajra, maize, *ragi*, wheat, barley and gram), sugarcane, cotton, jute and five oil seeds (groundnut, sesamum, castor seed, rape and mustard and linseed) are considered in this study and by regions. These crops covering 77 per cent of the total cropped area are major contributors to the national income from agriculture.[1]

PROGRAMMING RESULTS

The programming solutions provide many interesting details of potential land reallocation among crops within regions. However, space prevents us from presenting detailed data by regions and we emphasize a summary of results at the national level. Table I summarizes, at the national level, but built up from the regional patterns, the acreage and percentage distribution of major crops (*a*) during the base year and (*b*) under change in allocation allowed in the programming model. The restrictions allowing these percentage changes were, as mentioned earlier, applied by regions.

TABLE I—DISTRIBUTION OF ACREAGES AMONG DIFFERENT GROUPS OF CROPS FOR ALL REGIONS

(*in million acres*)

Commodity group	Under original distribution		Under programming solutions ±10% changes		±20% changes		±40% changes	
	Area	Dis*	Area	Dis*	Area	Dis*	Area	Dis*
Foodgrains	229.8	79.8	227.4	79.0	225.5	78.3	221.1	76.8
Sugarcane	5.2	1.8	5.7	2.0	5.7	2.0	6.2	2.2
Cotton	19.5	6.8	20.6	7.2	21.7	7.6	24.0	8.3
Jute	1.7	0.6	1.9	0.7	2.1	0.7	2.4	0.8
Oil seeds	31.7	11.0	32.3	11.2	33.0	11.5	34.2	11.9

* Percentage distribution.

Only foodgrains lose in acreage. Jute takes on the maximum acreage increase allowed and is followed closely by sugarcane. Cotton is third in this respect, showing moderate increases in acreages under each situation of allowed change. These three, plus oil seeds, draw their additional acreages from foodgrains.

1. The remaining area is covered by fodder, other pulses, orchards, etc. Bullock maintenance cost comes mainly from fodder raised on farms. Bullock labour does not form a part of restrictions of the model because it is in "over supply." To some extent the bullock labour and fodder acreages balance one another outside the model.

Increases in production and income suggested under the various solutions of our model are presented in Tables II and III. These results suggest the improvements in production or value of product under planning procedures which, given the specified objective function and the boundary conditions discussed earlier, more formally recognize the comparative advantage and interdependencies among regions. Even greater gains in production and income might be realized, had the model not restrained change for any one crop and region to 40 per cent. On an overall basis, the model solutions suggest some important increases in production and income if land were allocated by regions and crops as specified by our results. This gain might be as much as 12 per cent, as a result of formal planning models such as ours. The magnitude of improvement varies with the amount of change allowed by crop and region. When change is restricted to 10 per cent of the original or base period acreage the total increase in value of crop production specified for the nation is 3.5 per cent. However, when change of 40 per cent is allowed, the increase in value of production rises to 12.5 per cent. In general, the gain is expected to come from the collection of resources already in agriculture and does not imply large capital outlays except on irrigation. It results almost entirely from a reallocation of crop production to conform with regional production possibilities and comparative advantage.

TABLE II—PRODUCTION OF DIFFERENT COMMODITY GROUPS FOR ALL REGIONS

(*in million maunds*)

Commodity group	Under original allocation	Under programmed solutions					
		±10% changes		±20% changes		±40% changes	
		Quantity	Inc*	Quantity	Inc*	Quantity	Inc*
Foodgrains	1,876.7	1,903.5	1.4	1,934.1	3.1	1,991.4	6.1
Sugarcane	210.1	231.1	10.0	231.1	10.0	252.1	20.0
Cotton	79.2	84.1	6.2	89.1	12.5	98.9	25.0
Jute	21.9	24.1	10.0	26.3	20.0	30.6	40.0
Oil seeds	164.9	173.1	4.9	181.4	10.0	197.8	19.9

* Percentage increase over original production of existing pattern.

TABLE III—INCOME FROM DIFFERENT COMMODITY GROUPS FOR ALL REGIONS

(*in million rupees*)

Commodity group	Under original allocation	Under programmed solutions					
		±10% changes		±20% changes		±40% changes	
		Income	Inc*	Income	Inc*	Income	Inc*
Foodgrains	28,877.4	29,517.0	2.2	30,207.1	4.6	31,535.4	9.2
Sugarcane	3,402.7	3,742.9	10.0	3,742.9	10.0	4,083.1	20.0
Cotton	2,652.6	2,821.7	6.4	2,991.7	12.8	3,330.8	25.6
Jute	531.7	584.9	10.0	638.1	20.0	744.4	40.0
Oil seeds	3,202.1	3,351.5	4.7	3,503.8	9.4	3,805.1	18.8
Total	38,666.6	40,018.0	3.5	41,083.6	6.3	43,498.8	12.5

* Percentage increase over original income of existing pattern.

Improvements expressed as percentage in production and income of jute and sugarcane correspond exactly to percentage increases allowed in their acreages. When a 10 per cent change is allowed in acreage for each region, a 10 per cent increase in value of production is specified for each of these crops. It is interesting to note that though oil seeds have small percentage increases in acreage, income and production of this group exhibit sizable increases because of the substitution which takes place among the five crops.

The programming solutions for foodgrains specify a decrease in total acreage. However, because their production is allocated among regions more nearly on the basis of comparative advantage, production and income from them rise. The substitution among the eight foodgrains more than offsets decreases in acreages, in terms of total value of output produced. The crops which gain in acreage are generally "superior" foodgrains (rice and wheat) and losers are mostly "inferior" foodgrains (jowar and bajra). Hence, apart from increases in physical production the composition of the foodgrain mix is improved.

Production and income are given in Tables IV and V respectively for the regions. The programming solutions specify an increased income for all regions, though these increases are not uniform. Foodgrain production is increased in all regions except Assam, Gujarat, Maharashtra and West Bengal. The decline in foodgrain production in these regions is not large relative to increases in other regions and would create no substantial transport problems. (Foodgrains still are grown on 77 to 88 per cent of the total cropped area.)

TABLE IV—FOODGRAIN PRODUCTION IN DIFFERENT REGIONS

(units in million maunds)

Region	Under original allocation	Under programming solutions		
		±10% changes	±20% changes	±40% changes
Andhra Pradesh	152.4	157.8	163.4	174.4
Assam	43.8	43.7	43.7	43.7
Bihar	157.8	159.0	160.5	163.2
Gujarat	43.3	42.1	40.9	38.5
Jammu & Kashmir	12.8	13.0	13.3	13.7
Kerala	28.5	28.6	28.8	29.0
Madhya Pradesh	217.7	222.6	227.6	237.6
Madras	124.8	130.8	136.8	148.7
Maharashtra	166.5	164.5	162.6	158.7
Mysore	81.3	82.8	84.2	87.2
Orissa	104.0	104.6	105.2	106.4
Punjab	158.3	160.2	162.6	166.9
Rajasthan	114.0	121.1	128.3	142.6
Uttar Pradesh	319.0	320.2	323.8	328.5
West Bengal	143.4	143.3	143.3	143.2
Delhi	1.7	1.8	1.8	1.9
Himachal Pradesh	7.3	7.3	7.2	7.1
Total	1,876.7	1,903.5	1,934.1	1,991.4

TABLE V—INCOME IN DIFFERENT REGIONS

(*units in million rupees*)

Region	Under original pattern	Under programming solutions		
		±10% changes	±20% changes	±40% changes
Andhra Pradesh	3,335.9	3,526.8	3,693.8	4,051.4
Assam	755.9	769.8	778.6	800.9
Bihar	3,227.9	3,301.5	3,356.5	3,485.1
Gujarat	1,861.0	1,958.1	2,052.2	2,243.4
Jammu & Kashmir	195.3	200.6	205.7	216.0
Kerala	421.5	423.4	424.1	426.8
Madhya Pradesh	3,665.4	3,748.2	3,826.8	3,988.2
Madras	2,898.9	3,009.8	3,108.6	3,317.9
Maharashtra	3,740.6	3,848.8	3,923.5	4,106.4
Mysore	1,968.4	2,070.8	2,157.4	2,346.4
Orissa	2,112.1	2,126.2	2,138.3	2,164.3
Punjab	2,921.5	3,047.2	3,148.7	3,375.9
Rajasthan	1,808.7	1,924.3	2,036.9	2,265.2
Uttar Pradesh	6,417.8	6,691.1	6,830.5	7,243.2
West Bengal	3,187.8	3,221.0	3,249.1	3,310.1
Delhi	27.8	28.9	29.9	32.1
Himachal Pradesh	120.2	121.5	122.8	125.4
Total	38,666.6	40,018.0	41,083.6	43,498.8

Regional income restrictions and national availability constraints were not binding in the solutions. δ_L, P_f, P_s, P_c, P_g and P_o thus are all zero and indicate that the programming results make each region "better off" in income. That the regional prices used are in conformity with the composition of the agricultural production which "must be produced." Further, using the level of technologies at the end of the Second Plan period, the programming increases in production fall short of the food production goals projected for the end of the Third Plan. Hence, the programming results would not create conditions of "lack of demand," especially in a nation which still is greatly in need of food.

Dual Relationships

Since restrictions of types 5-10 are not binding, relation 13 in the dual solution simplifies to :

$$\gamma^L - \gamma^L_{j\,(min)} + \gamma^L_{j\,(max)} = C^L_j.$$

The optimal programming solution for the allowed ± 10 per cent changes in acreages was attained with 151 iterations. The basis did not change for higher changes in acreages ($\pm$ 20 per cent and $\pm$ 40 per cent). Hence, the values of γ^L, $\gamma^L_{j\,(min)}$ and $\gamma^L_{j\,(max)}$ are the same for all solutions. The detailed study of these "rents" in each region for different crops would help in a study of regional specialization in agriculture which, however, falls outside the scope of this paper. Table VI gives a summary statement of the regional (general) rents. As an example, numerical rent per acre in rupees for particular crops is as follows :

Andhra Pradesh (sugarcane)

$$\gamma^L + \gamma^L_{j\,(max)} = C^L_j$$

$$97.889 + 1,245.639 = 1,343.528$$

Assam (maize)

$$\gamma^L - \gamma^L_{j\,(min)} = C^L_j.$$

$$126.753 - 68.113 = 58.640$$

TABLE VI—GENERAL RENT (GROSS) PER ACRE

(*in rupees*)

Region	General rent (gross) γ^L	Region	General rent (gross) γ^L
Andhra Pradesh	97.9	Maharashtra	88.8
Assam	126.8	Mysore	62.3
Bihar	176.7	Orissa	205.5
Gujarat	120.2	Punjab	122.7
Jammu & Kashmir	121.5	Rajasthan	38.0
Kerala	204.0	Uttar Pradesh	92.0
Madhya Pradesh	104.8	West Bengal	251.1
Madras	214.4	Delhi	107.8
		Himachal Pradesh	149.4

Another interesting relation brought out by regional general rents is that differential rents per acre for different regions can be estimated as :

$$\gamma^J - \gamma^L_{(min)} = \gamma^J_{(diff)}.$$

$\gamma^J_{(diff)}$, the differential land rent per acre in region J is equal to general rent in region J (γ^J) minus the general rent in a region where it is minimum among all regions. The minimum general rent in our case is Rs. 38.026 for Rajasthan. Hence, the differential rent per acre for Punjab is 122.696—38.026 = 84. 670.[2]

2. This rent is somewhat different from the classical definition of differential rent. The minimum rent in the case of classical theory is zero, whereas it is a positive figure here. Further, in this case there is more than one market.

APPLICATION OF PROGRAMMING MODELS IN PLANNING

Our results, while obviously having limitations, suggest gains to be forthcoming when formal programming models and computation facilities are used in formulating and analyzing plans. It is likely that our results, while showing some important increases in production and income from essentially the same resources, greatly understate the possible gains from more detailed application of formal programming or planning models. It was necessary for us to use extremely broad regions. Further stratification of regions and designation of their relative production possibilities for various crops may have given more useful indications. Similarly, we did not consider new technologies in this study.

Actually substantial improvements in yield per acre of different crops are envisaged in the Third Five-Year Plan through technological improvements and their extensive application. These estimates of increases in yields have not been broken down by regions. It was, therefore, not possible to include the improvements in technologies as alternative activities or investment opportunities in various regions. However, these alternative technologies were simply used as "goals to be put into effect," without consideration of interactivity and inter-regional competition, in the informal planning methods used in constructing the Third Plan. The interaction of regions, new technologies and national food targets can be considered only through planning models such as ours and which allow use of large capacity computors. We expect that these opportunities will exist in the future for all countries concerned with national planning of agriculture. In previous Five-Year Plans of India, regional plans were considered, but largely in terms of the potential for each region apart from others. Since formal models and large scale computors were not available or were not used, it was essentially impossible to make calculations which considered the interdependencies among regions (in contrast to a more simple determination of whether each individual region could increase its output). We believe that our results suggest the gains possible in plans devised through programming models and which may use computors to consider regional inter-relationships.