A Spatial Equilibrium Model for Plant Location and Interregional Trade

Matthias von Oppen and John T. Scott

Combination of a single-equation location model and interregional trade analysis into one model provides an effective tool to simultaneously determine regionally optimal numbers and sizes of processing plants and optimal interregional trading and pricing. The results of an earlier empirical application of the model on the prospective soybean industry in India are reviewed after four years of actual development. Private industry is allocating its processing plants in line with the pattern computed by the model, and a comparatively costly plan of arbitrarily establishing one government plant at an arbitrary location has not been implemented.

Key words: agricultural industry, India, interregional trade, location theory, soybeans.

The general theory pertaining to the spatial location of economic activity can be divided, according to Hoover, into the following three classes: location, regional analysis, and interregional trade. Location theory describes the economic analysis involved in comparing alternative spatial locations for a specified kind of activity, while regional analysis is "concerned with groupings of inter-related economic activities in proximity within certain specified areas" (Hoover, p. 3). Interregional trade refers to the buying and selling of inputs or products and their movement among two or more delineated areas.

Highly sophisticated methods and approaches have been separately developed in each of these fields of spatial economic theory. However, apparently few attempts have been made to integrate these theoretic fields, especially the theory of location and interregional trade analysis, or to integrate their associated models (Candler, Snyder, and Faught; Leuthold and Bawden; Rao; Stammer).

There are an increasing number of cases in which public decision makers, especially in developing countries, are concerned with the question of implementing a new, efficient agricultural industry (from raw materials production to processing and marketing of final products) so that social welfare can be maximized. To solve such a problem requires investigations in two fields: (*a*) an analysis of the interregional trade in order to predict the flows of the new goods, the quantities demanded regionally, and the resulting price level; and (*b*) a determination of optimal locations and sizes of individual processing plants. Therefore, we believe that an approach integrating the theory of location and interregional trade analysis will be of general interest. The model presented here was developed to represent the emerging soybean industry in India (von Oppen 1972), but it could be adopted to almost any agricultural production and processing industry.

The Model

The spatial equilibrium model for location of processing plants integrates all of the following important economic functions: (*a*) transportation of inputs and products, (*b*) average processing cost related to plant size, (*c*) size of market area per plant, (*d*) regional supply functions of inputs to be processed, and (*e*) regional consumer demand functions for processed products. The model is constructed in two parts: the plant location is determined with the help of a single equation optimization model and the interregional trade of inputs and products is analyzed by means of a quadratic

Matthias von Oppen is a senior economist with the International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India, and John T. Scott is a professor of agricultural economics at the University of Illinois, Urbana-Champaign.

This paper was developed from research supported in part by the Agency for International Development and the Illinois Agricultural Experiment Station, Urbana. The authors thank Folke Dovring and T. Takayama, University of Illinois, as well as J. G. Ryan and H. P. Binswanger, International Crops Research Institute for the Semi-Arid Tropics, for their helpful suggestions.

programming model. From the optimum solution of the plant location, model regional average processing costs are derived and fed into the interregional trade model. From the optimum solutions of interregional trade model, the quantities to be processed and distributed by processing plants are derived and fed into the plant location model. If applied in this fashion, both models are linked by an iterative solution procedure and jointly form a spatial equilibrium model for plant location and interregional trade (figure 1).

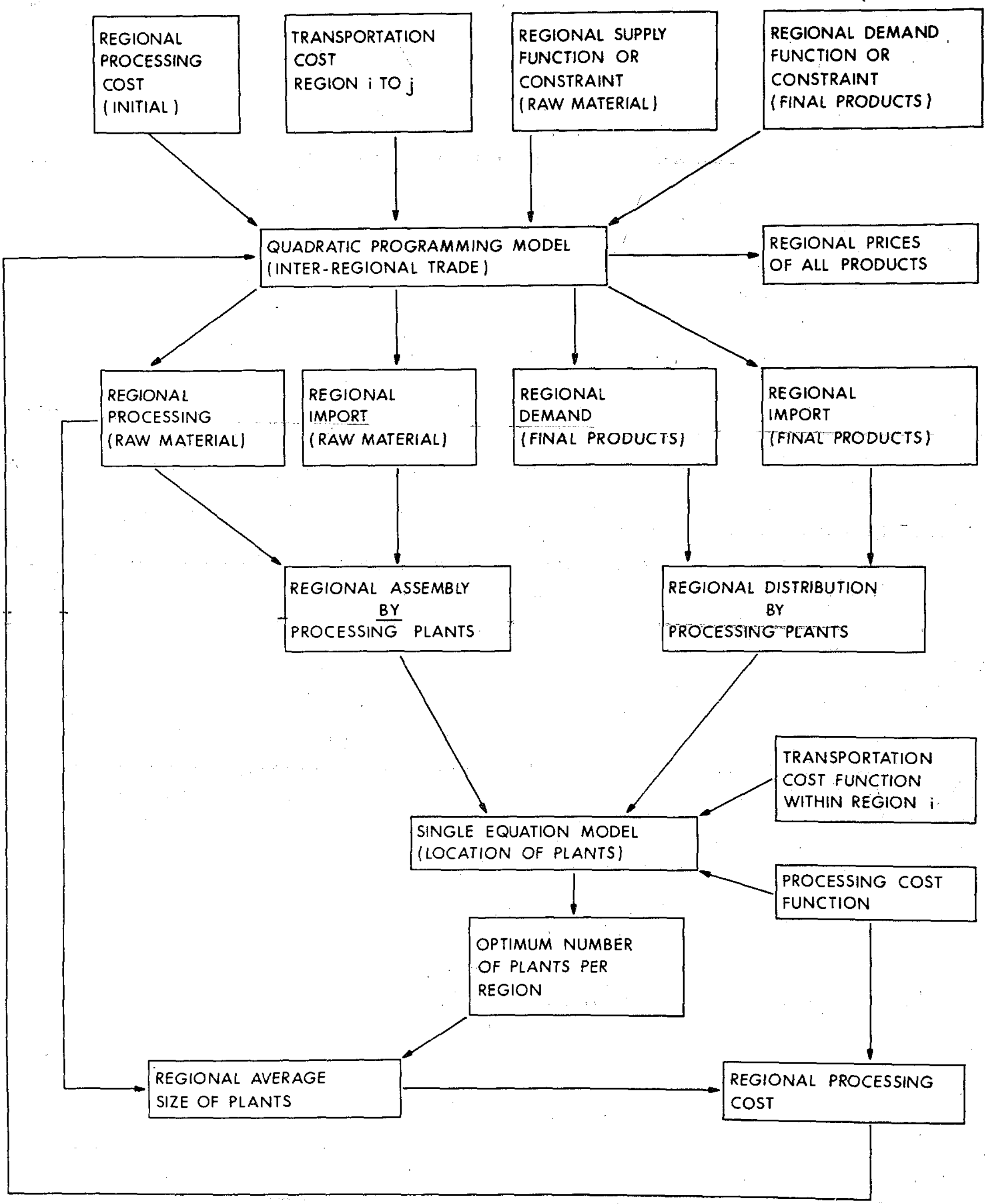

Figure 1. Flow chart of a spatial equilibrium model for plant location and interregional trade

Plant Location—Assembly, Processing, and Distribution

The location equation is based on the following assumptions: (*a*) as the number of plants within a region increases, average processing costs will increase at a linear rate; (*b*) both the average assembly and distribution costs of the major inputs and products in the market area of a plant decrease at a decreasing rate as the number of plants in a region increases; (*c*) the assembly and distribution road network fits approximately a 60° triangular grid such that hexogonally-shaped plant market areas within regions are appropriate; and (*d*) within a region, producers of inputs for the plant and consumers of products from the plant are evenly distributed.[1]

Furthermore, as the number of plants is initially increased (from the number at which plant size is large enough that average processing cost is a minimum), the sum of average assembly and distribution costs decreases faster than the increases in average processing cost. As the number of plants continues to increase, however, processing costs begin to increase faster than the decrease in assembly and distribution costs. The optimum number of evenly distributed plants is determined by the minimum of the sum of these average cost functions.

Given these assumptions, the plant location equation can be derived as follows:

$$B = 6\frac{r^2}{4}3^{1/2}, \tag{1}$$

where B = the hexagonal market area for a plant and r = the circumscribing radius of the hexagon. If A is the total area of the region for which the optimum number of plants is to be found and N is the number of plants, the area per plant can be explained as

$$B = \frac{A}{N} \tag{2}$$

Solving equation (1) for r and substituting equation (2) into (1) gives

$$r = 0.6204\left(\frac{A}{N}\right)^{1/2} \tag{3}$$

for the radius of each of the N hexagons representing the market areas of the plants in the region. The average distance from all points evenly distributed within the hexagon to the central point for assembly and distribution can be shown to be $0.7r$.

We assume that assembly of raw material and distribution of final products have the same per unit costs and these are a linear function of the average distance from the plant with an initial fixed cost for loading or unloading and vehicle use, so that

$$T = f + d\,(0.7r), \tag{4}$$

where T = the transportation cost per unit of input or product, f = the fixed cost, and d = the per unit cost of transportation per unit distance.[2]

The quantities of raw materials (R) to be assembled for processing and the quantities of final products (M) to be distributed for consumption within the market area of the plant can be expressed in relative terms using as a common denominator the quantity regionally available for processing (Q).[3] Relative weights of the quantities transported within the market area of a plant are required to form the sum of the transportation cost functions for both of these quantities before adding the processing cost function. Thus, after substituting equation (3) into equation (4) and multiplying by the relative weights, the regional assembly cost function for locally assembled input R becomes

$$T_1 = T\frac{R}{Q} = f_1\frac{R}{Q} + (0.43)\,d\left(\frac{R}{Q}\right)A^{1/2}N^{-1/2}, \tag{5}$$

and the regional distribution cost function for locally distributed final product M becomes

$$T_2 = T\frac{M}{Q} = f_2\frac{M}{Q} + (0.43)\,d\left(\frac{M}{Q}\right)A^{1/2}N^{-1/2}. \tag{6}$$

The average regional processing cost is assumed to be

$$T_3 = f_3 + c\,\frac{N}{Q}, \tag{7}$$

[1] This assumption is perfectly fulfilled only in the case of perfectly homogeneous (i.e., for all practical purposes, very small) regions. However, even in the case of larger regions with urban population concentrations, the assumption may still be acceptable and realistic as long as these urban areas as such are evenly distributed.

[2] Where assembly and distribution are carried out by truck and as long as the commodities concerned are not extremely bulky, perishable, or otherwise difficult to be transported by truck, their freight rates normally are based on the same per quintal charge.

[3] Note that Q includes regional production adjusted by imports and exports of the region as determined from the interregional trade portion of the model (see figure 1).

where N/Q = the reciprocal of average plant capacity, and the processing cost is assumed to be a function of the reciprocal of the quantity processed.[4] Then summing the three functions (5), (6), and (7) and setting the first derivative of this sum with respect to N equal to 0 gives the number of plants (N^*) that according to the second order condition minimizes assembly, processing, and distribution costs:

$$(8) \quad N^* = \left(\frac{0.43}{2} \frac{d}{c} (R + M)\right)^{2/3} A^{1/3}.$$

This shows that the optimum number of plants is a linear homogeneous function of degree one in the two variables—the sum of inputs assembled and products distributed and the area of the region. This optimum number is then theoretically located by evenly distributing the plants within the region.

Interregional Trade—Regional Supply and Demand Functions

The basic concept of this model is a special case of the general problem of nonlinear programming, which is solved for the saddle point (Takayama and Judge 1971). In this case the objective function is a quadratic function constrained by linear inequalities, a problem that has a unique solution (Takayama and Judge 1964).

The major assumptions and the economic environment are as follows. A given country is divided into n regions. Each region is represented by one base point at which the supply of primary product, the demand for the final products, and the processing capacity are assumed to be concentrated. All possible pairs of regions are separated by known transportation costs per physical unit for each product. The processing capacity in each region is assumed to be unlimited. Processing is performed at per unit costs that are assumed to be given for each region (from above). Demand for each of the final products is assumed to be known for each region and to be a logarithmic function of price.[5] For each of the n regions a nonnegative quantity of the primary product is given.

[4] This functional form is suitable for estimating average cost functions of production processes where economies of size imply that with increasing capacity processing costs are asymptotically approaching a minimum value.

[5] For programming purposes this nonlinear function is assumed to be represented by its linear tangents. The incorporation into the model of the procedure for selecting the representative tangents is described in note 6.

In this environment it is possible to formulate a model that accounts for the interaction of the spatially separated economic units. The model determines the level and location of processing of the primary product into final products, gives volume and direction of all product flows that will minimize the aggregate transportation and processing cost, and finally determines the pricing system of all products that accompany the optimum allocation system.

Regional demands for final commodities Y are assumed to be represented by functions dependent on price P. These are of the general form $P = aY^{-b}$. Their tangents represent linear demand functions for the final products in each region. By applying the familiar technique of formulating the "net" social benefit function as the sum of the line integrals of individual demand relations minus the total costs of processing and transportation, a quadratic spatial equilibrium problem can be set up (Takayama and Judge 1971). The objective of this problem is to maximize the "net" social benefit subject to a set of constraints on primary commodity allocation and flows; final commodity production, flows, and consumption; and processing and joint production. All prices and quantities are restricted to be nonnegative.

If the assumptions of the net benefit function and the constraints are satisfied, then a necessary and sufficient condition for an optimum solution to the problem is that the corresponding Lagrangian forms a saddle point. The appropriate Kuhn-Tucker conditions ensure that the solution is a maximum (Takayama and Judge 1964).

Combination of the Model Parts

When the two models are applied jointly, it is assumed that interregional flows take place between regional centers (reference points), while in reality, of course, shipments would flow from all plant centers or local assembly points (in case unprocessed raw products are shipped) to consumption centers. This assumption is justified because it implies realistically that the sum of the costs of all shipments between all pairs of plant centers and assembly points in region i and consumption centers in region j does not, or only to a negligible extent, differ from the costs of shipment between the regional centers of regions i and j.

In combining the two parts of the model into one spatial equilibrium model, the following concept is applied. Assume that there are two systems that are mutually dependent in that the output of one constitutes part of the input of the other. Then, as these systems are optimization models, they form a combined equilibrium model. Their interdependence generates a sequential set of objectives and restrictions, the objective of the plant location model forming a restriction to the interregional trade model and the objective of the interregional trade model forming a restriction to the plant location model. In other words, for each of the two models the optimum solution is to be found subject to the constraint that the other model be optimized. Since part of the input of the model is generated by the other model, a sequence of alternating applications of both models—one in the objective, the other in the constraint, and vice versa—asymptotically approaches an equilibrium solution.[6] We assume that the solution is unique because each of the two parts of this model has a unique solution. Application of the model with empirical data showed consistent convergence of these solutions.[7]

6 The spatial equilibrium model consists of the following programs: (*a*) quadratic programming model (*QP*), (*b*) single-equation plant location model (*SE*), (*c*) derivation of regional demand functions from a tangent to the exponential demand function (*DT*), and (*d*) testing of the tangent for representativeness and if rejected finding new tangent (*TT*). In applying these programs in the empirical case given below. The most efficient sequence was found to be

$$\begin{array}{l} SE_1 \searrow \\ \qquad QP_1 \rightarrow SE_2 \rightarrow QP_2 \rightarrow TT_1 \rightarrow QP_3 \rightarrow SE_3. \\ DT_1 \nearrow \end{array}$$

7 The uniqueness of the solution depends upon the character of the set of the various parameters included. In the unlikely but conceivable case in which the parameters included generate nonconvergence of the results (e.g., when the sum of the costs of transportation of the raw materials equals the sum of the costs of the transportation of the final commodities), there would be no unique optimal solution to the problem. By submitting the model to appropriate sensitivity tests, the likelihood of such cases can be evaluated.

An Empirical Application

While there is a sophisticated oilseed processing industry established in India, soybean production, processing, and consumption is a new developing sector in this country. After their introduction in the late 1960s, cream-colored varieties of soybeans covered about 10,000 hectares in 1970–71 and about 43,000 hectares in 1973–74. In 1974, five solvent-extraction plants with a total capacity of 265 tons per day and five screw-press-expeller plants with a total capacity of 11 tons per day were reported to be processing soybeans in India (see table 1).

In view of this development it seems worthwhile to review the results that were generated in 1971 by the above spatial equilibrium model of a future Indian soybean economy based on data collected in 1970–71 (von Oppen 1972). The following is a summary of the major assumptions made on supply demand, transportation, and processing of soybeans (von Oppen 1972, 1974).

Based upon certain agronomic assumptions about the general production potential for soybeans in India, about the extent to which a selected number of crops and fallow land might be substituted by soybeans, and about

Table 1. Soybean Processing Facilities Reported in Different Regions in India—1974

	Region							
Plant Type	1	2	3	4	5	6	7	All-India
Screw-press expeller								
Number	—	1	—	2[a]	—	1	3	5
Average capacity (tons/day)	—	4	—		—	4	1	2.2
Annual capacity (tons)	—	800	—		—	800	600	2,200
Solvent extraction								
Number	—	1	—	1	—	2	1	5
Average capacity (tons/day)	—	60	—	60	—	10	125	53
Annual capacity (tons)	—	18,000	—	18,000	—	6,000	37,500	79,500
Total annual capacity (tons)	—	18,800	—	18,000	—	6,800	38,100	81,700

Source: Rathod and Motiramani 1974.
[a] One extrusion cooker and one soymilk plant, both still in the experimental stage.

yield, the potential production of soybeans by districts was computed (see figure 2); coterminous districts of homogeneous potential production densities were grouped into seven regions and the share of each region in the total potential production was calculated.[8]

The two joint products, soymeal and soyoil, were assumed to be substitutes for gram flour and groundnut oil, respectively, for each of which demand functions were fitted using time-series data on prices, quantities consumed per capita, and income per capita. The per capita demand for gram flour was estimated, and after conversion into the required form it became

$$P_g = 1.5716\ Y_g^{\ -0.84048},$$

where P_g = price of gram in rupees per kilogram and Y_g = the quantity of gram consumed in kilograms per capita.[9]

The per capita demand for groundnut oil used by the vanaspati[10] industry was estimated, and after conversion into the required form it became

$$P_o = 0.001955\ Y_o^{-1.8298},$$

where P_o = the price of groundnut oil in rupees per kilogram and Y_o = the quantity consumed in kilograms per capita.[11] The demand functions entered into the model were defined as tangents uniquely representing these exponential functions. Regional demands were then derived by dividing the slope of the soymeal demand by regional population, by dividing the slope of the soyoil demand from the vanaspati industry by regional population proportional to vanaspati industry prevailing in each region, and by adjusting the intercept of the soyoil demand function according to the postulated per capita income.[12]

The average costs of processing in solvent extraction plants were estimated from engineering data and found to be $T_3 = 59.95 + 1383.5\ S^{-1}$.[13] Assembly of soybeans from the farmer to the plant and distribution of soymeal from the plant to the consumers was assumed to be carried out by truck; truck rates were found to be a linear function of distance. The intraregional transport was assumed to be carried out by rail according to freight rates for the different commodities in 1970–71.

Table 2 summarizes the major assumptions made with respect to time. The years 1970–71, 1973–74, 1978–79, and 1988–89 are labeled model years A, B, C, and D, respectively. Estimates of the Indian population are taken from official sources. Estimates of income per capita are based on an average annual income between 1964 and 1969 and a compound growth rate of 2% annually during the entire period is assumed. Table 2 also gives the most recent data available on the actual development in 1971 and 1973.

Comparison of the actual development with the model years indicates that in 1973 population, income, and soybean production have developed about three years past the model year A and are about five years "away" from model year B. Therefore, the results (table 3) for model years A and B should be comparable with the actual location and size of soybean processing plants; if so, the results for the later model years C and D would allow one to draw useful conclusions.

Average processing capacity of soybean solvent extraction plants was calculated by the model to grow about 50 tons per day in year A to about 140 tons per day in year B, eventually reaching up to 350 to 400 tons per day in year D. Present capacities of the five solvent extraction plants for soybeans of 53 tons per day seem to be quite in line with this result, even though they range from 10 to 125 tons per day (table 1).

The existing processing plants are located in regions 2, 4, 6, and 7, which is partly in line with our predictions. In contradiction to the

---

[8] Formulation of the interregional trade of a soybean economy (one raw product, two final products) into a quadratic programming model as specified above requires a matrix for n regions of $n \times 7$ rows and $n \times 23$ columns. Seven regions were chosen because on the one hand a larger number of regions would have required excessive computational costs and on the other hand less than seven regions would not have allowed a satisfactory division of the country into reasonably homogeneous areas.

[9] The function was estimated by using seventeen years of All-India per capita net availability and annual average prices of gram (Government of India 1968, 1970, and 1973). The standard error of the exponent is 0.1812, the coefficient of multiple correlation is 0.76, and the F-ratio is 21.5.

[10] Vanaspati, hydrogenated vegetable oil, is commonly used as cooking margarine in India.

[11] The estimation was based on monthly observations for five years (1964 to 1969) on per capita groundnut oil consumption (Q_o), groundnut oil prices (P_o), and per capita income expressed in vanaspati consumption per capita (V_c) (Government of India 1964 to 1969). After adjusting for an autocorrelation of 0.6, the logarithmic function fitted gives

$$\ln Q_o = -0.8590 - \underset{(0.4004)}{\ }\ 0.5465 \ln P_o + 0.653 \ln V_c.$$
$$(0.4004)\quad (0.2213)\quad (0.254)$$

Standard errors are given in parentheses. The coefficient of multiple correlation is 0.37 and the F-ratio is 5.3.

[12] Division of the slope of the soymeal demand by population implies multiplication of the per capita quantity and thus aggregation of the demand function.

[13] Where S represents annual capacity in tons, note that $S = QN^{-1}$.

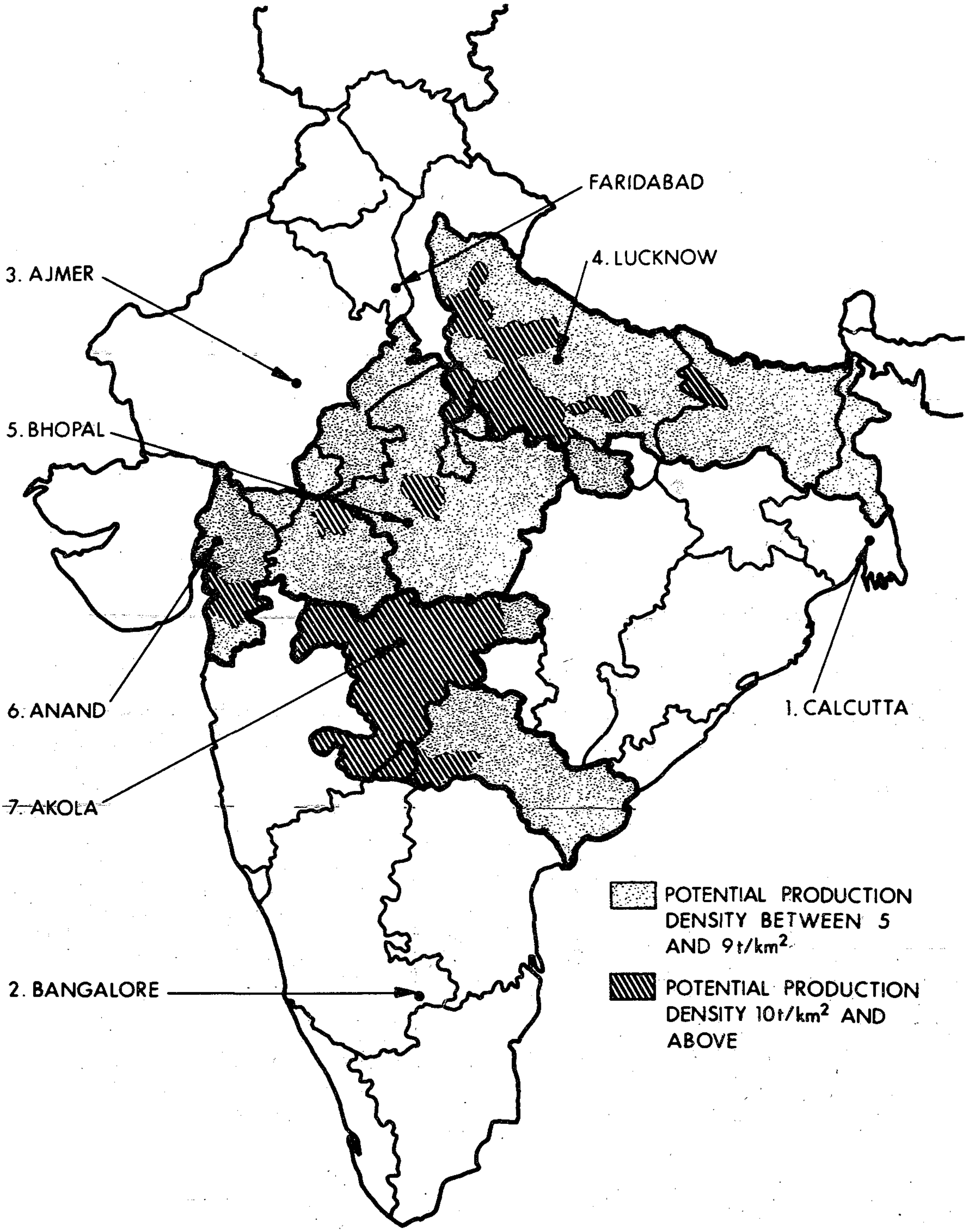

Figure 2. Estimated soybean production potential and demarcation of regions and reference points in India

model result, there is no processing capacity for soybeans in region 5 as yet, while in region 2 soybeans are processed. This can probably be explained by the fact that a reclassification of rail rates in 1973 resulted in a reduction of the rates for soybeans and a substantial in-

Table 2. Assumed and Actual Development in Population, Income, and Soybean Production

Item	Assumed Development in Model Years				Actual Development	
	A	B	C	D	1971	1973
Population in millions	550	592	662	787	551	574
(1968–69 = 100)	(105.0)	(113.0)	(126.3)	(150.2)	(105.2)	(109.5)
Income at 1960–61 prices						
in Rs. per capita	337.0	357.6	394.8	480.9	345.8	337.5
(1968–69 = 100)	(104.0)	(110.4)	(121.9)	(148.6)	(106.8)	(104.2)
Soybean area in ha. (or tons)[a]						
Region 4	7,280	145,600	436,800	1,820,000	4,909	16,820
Region 5	4,190	83,800	251,400	1,047,000	5,122	17,077
Region 6	2,610	52,300	156,900	653,000	2,935	8,827
Region 7	5,920	118,300	354,900	1,480,000	11,254	532
All-India	20,000	400,000	1,200,000	5,000,000	24,220	43,256

Sources: Rathod and Motiramani 1974; Government of India.
[a] Assuming yields are 1 ton/ha.

crease in the rates for soymeal and in making soybean processing feasible also in non-producing regions such as region 2.[14]

Without entering into further discussion of the many reasons why or why not reality differs from the model results in some cases, it can be concluded from the evidence gathered so far over the short period of three years that the soybean economy in India appears to be generally allocating plant capacities and sizes in line with the optimality criteria developed in the model. It should be mentioned here that for several years plans existed to establish one single government-operated processing plant with an initial capacity of about 100 tons per day and a provision to later step up the capacity. This plant was planned to be located in Faridabad, south of New Delhi (Rathod and Motiramani 1974). If only one plant had been available to process the quantities of model years A and B so that interregional trade would have been forced to move soybeans to Faridabad and if soyoil and soymeal were distributed among regions according to the quantities demanded in model years A and B, then this arbitrary solution would have cost the soybean economy in year A about 130% and in year B about 186% of the costs for the optimum solutions (see table 4).

It should be emphasized that starting a soybean economy in India imposes the "chicken-and-egg" problem of simultaneously developing raw material production and processing facilities. If left to itself, this problem will probably be solved by an industry that especially in the initial stages is expanding at very low rates and at the costs of likely mistakes resulting from trial and error approaches. However, with the help of a tool such as the above, despite its many limitations some of the major principles involved in the spatial allocation of the soybean processing industry are recognized and can be applied for future planning by both public and private decision makers in order to foster the growth of the soybean industry.

[14] The ratio of the sum of the costs of transporting soymeal and soyoil over the sum of the costs of transporting soybeans increased from 0.52 in 1970–71 to 0.75 after 1973.

Table 3. Theoretical Optima of Number, Average Capacity, and Average Radius of Market Area of Soybean Processing Plants in Four Model Years

Model Year	Region 4	5	6	7	All-India
	Number of Processing Plants[a]				
A	0.5	0.3	0.2	0.4	1.4
B	3.8	1.9	1.2	2.4	9.3
C	7.7	3.7	2.3	4.7	18.4
D	19.3	9.5	5.9	12.0	46.7
	Average Capacity (tons/day)				
A	47	45	47	51	48
B	127	147	145	163	143
C	189	224	224	250	217
D	314	368	370	413	357
	Average Radius (km.)				
A	507	531	504	471	—
B	187	215	197	189	—
C	132	153	141	135	—
D	83	96	89	85	—

[a] The fractional numbers presented here as theoretical optima should for practical purposes be rounded upward, such as to give "recommended" numbers.

Table 4. Comparison between the Costs of Processing and Transportation of the Optimal Solution and of an Arbitrary Solution

	Optimum Solution (million rupees)		Arbitrary Solution (million rupees)		Optimum Solution Divided by Arbitrary Solution	
Costs[a]	Year A	Year B	Year A	Year B	Year A	Year B
Processing cost	2.64[b]	27.85[c]	1.60[d]	23.80[e]	0.61	0.85
Transportation cost of interregional trade	0.14	7.46	2.04	42.13	14.10	5.60
Total cost	2.78	35.31	3.64	65.93	1.30	1.86

[a] Based on 1970–71 processing costs (von Oppen 1972) and rail rates (Indian Railway Conference Association).
[b] Assuming one plant in each production region with capacities as indicated: region 4: 25 tons/day, region 5: 15 tons/day; region 6: 10 tons/day; and region 7: 20 tons/day, i.e., in total, 70 tons/day.
[c] Assuming average processing costs as indicated in table 4.
[d] Assuming one plant with a capacity of 70 tons/day.
[e] Assuming one plant with a capacity of 1,333 tons/day.

Conclusion

With the aim to contribute to the integration of location theory and of interregional trade theory, a model for plant location and interregional trade was developed. Application of the model on data relevant to a projected soybean industry in India produced feasible results. There is evidence that the actual development in the soybean processing sector up to 1974 has followed the earlier projected path fairly closely. It can be shown that an arbitrary plan of processing soybeans in one single plant located in a consumption region would raise costs to the industry 30% above the optimum level for 1970–71 and 86% above the optimum level in 1978–79. Application of the spatial equilibrium model for plant location and interregional trade may help decision makers to recognize the principles involved in the spatial allocation of agriculture-based processing industry and thereby reduce costs and time required for its development.

[*Received September 1975, revision accepted March 1976.*]

References

Candler, W., J. G. Snyder, and W. Faught. "Concave Programming Applied to Rice Mill Location." *Amer. J. Agr. Econ.* 54 (1972):126–30.

Hoover, E. M. "The Partial Equilibrium Approach." *Spatial Economic Theory*, eds. R. D. Dean, W. H. Leahy, and D. L. McKee, pp. 3–14. New York: The Free Press, 1970.

India, Government of, Ministry of Food, Agriculture Community Development and Cooperation, Directorate of Economics and Statistics. *Bulletin on Food Statistics, 18th, 20th, and 23rd Issues*. New Delhi: Government of India Press, 1968, 1970, and 1973.

———. *Oilseeds Situation*. Mimeographed. New Delhi: Government of India Press, monthly 1964 to 1969.

Indian Railway Conference Association. *Goods Tariff No. 32*. Calcutta: Eastern Railway Press, 1972.

Leuthold, R. M., and D. L. Bawden. *An Annotated Bibliography of Spatial Studies*. Exp. Sta. Res. Rep. 25, College of Agriculture, University of Wisconsin, Aug. 1966.

Rao, A. S. "Buffer Storage Location under Economies of Scale." *Indian J. Agr. Econ.* 28 (1973):14–29.

Rathod, K. L., and D. P. Motiramani. *Status of Soybean Industry in India*. All-India Coordinated Soybean Research Project, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, India, 1974.

Rathod, K. L., and D. P. Motiramani, eds. *Soybean Marketing Information*. Directorate of Research Services, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, India, 1970–74, quarterly.

Stammer, R. W. "A Mathematical Model for Determining the Optimum Spatial Organization of a Multi-Plant Industry." Ph.D. thesis, University of Connecticut, 1971.

Takayama, T., and G. G. Judge. "An Inter-regional Activity Analysis Model for the Agricultural Sector." *J. Farm Econ.* 36 (1964):349–65.

———. *Spatial and Temporal Price and Allocation Models*. Amsterdam: North-Holland Publishing Co., 1971.

von Oppen, Matthias. "Optimal Size and Location of Marketing Facilities for Soybeans in India." Ph.D. thesis, University of Illinois, 1972.

———. *Soybean Processing in India: A Location Study on an Industry to Come*. INTSOY Ser. No. 4, College of Agriculture, University of Illinois, July 1974.