THE PRODUCTION LOCATION PROBLEM AND THE DEVELOPMENT OF INDUSTRIES ON A REGIONAL BASIS IN THE ASEAN COUNTRIES

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I. INTRODUCTION

RECENTLY the idea of a group of less-developed countries cooperating in the establishment of large-scale, capital-intensive industries or what is sometimes referred to as complementation schemes, has become a quite imminent possibility among the countries of the ASEAN region. The Association of Southeast Asian Nations, or ASEAN as it is popularly known, comprises five countries: Malaysia, the Philippines, Thailand, Indonesia, and Singapore and was created in 1967. At present the subject of ASEAN regional[1] cooperation in the development of specific industries is being seriously discussed at both the ministerial and head of state levels. In addition to this quite favorable political climate, which is an essential pre-requisite for the establishment of industries on a regional basis, there is the fact that the proximity of these countries, their quite similar development problems and their common development strategies tend to make regional industrial cooperation among these countries a generally sound economic policy. All are heavily reliant on ocean shipping and use Singapore as a major transshipment point: with the exception of Singapore, all are actively involved in efforts to diversify their production and to reduce dependence on a few raw material export products; and all are to some extent constrained, some more than others, in achieving this goal by their presently small domestic markets.

Despite this apparent interest at a high policy-making level and the *prima facie* economic case for such schemes, the economics of how to establish specific industries on a regional basis among the ASEAN countries has not received the attention that it should.[2] This paper deals with this question. It is directed specifically at the problem of determining the optimum locations and sizes for

The views expressed in this paper are the author's own and should not be attributed to the IBRD.

[1] It should be noted that the term regional as it is being used here means multi-national and not a sub-national area as it is often regarded.

[2] There are two studies which have attempted to deal with this problem; one, within the context of the ASEAN region and the other, within a somewhat larger geographical area comprising the ASEAN countries among others [13] [14]. Both studies only suggest possible geographical distributions of industries without demonstrating the superiority of the particular solution recommended.

plants within specific decreasing cost industries which the countries of the ASEAN region could and might benefit from developing on a regional basis. A linear programing model is used for this purpose, the results of which are adjusted for distributional considerations in order to minimize possible conflicts of interest between the participating countries and thereby preserve the political stability of the arrangement. Two industries are tested: aluminum and urea fertilizers.

II. THE SELECTION OF INDUSTRIES

The basic rationale for developing certain industries on a regional basis is that: (1) industries with economies of scale require larger markets than often exist within a single country; (2) the extra-regional market (outside the ASEAN region) may be too uncertain, too competitive or too prohibitive in terms of trade restrictions to guarantee that the domestic surplus can be marketed; (3) the absolute capital and related infrastructure costs of building such large plants so that economies of scale may be realized, may be too prohibitive for a single country; and (4) a single country may not possess the necessary managerial and technical expertise.

The aluminum and urea chemical fertilizer industries were selected to test the model because they possess several of the above characteristics and, therefore, their development could be expected to be a substantially more economical proposition at the regional rather than at the national level.[3] Both the aluminum and urea fertilizer industries are among the major import industries for the ASEAN countries and are, therefore, found largely outside this region. In fact, regional industrial cooperation may be regarded as a policy of import substitution not at the national but at the regional level, where, because of a regional demand and joint investments, it may be economically feasible. Because industries, which require a heavy fixed capital investment and large regional demand are not likely to become the candidates for import substitution by countries acting independently, the regional planning of such industries should be that much more politically acceptable.

III. THE LINEAR PROGRAMING MODEL

The objective of the model is to find that geographic distribution of plants which meets a fixed geographic distribution of demand for a given product at minimum total cost (transport plus production costs) to the region. The distribution of plants which satisfies this condition is said to be optimal. To determine this optimum plant distribution for an industry, one must know the quantity demanded

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[3] Other industries which would have been equally appropriate for treatment in this study include, among others: iron and steel, pulp and paper, agricultural tractors and implements, shipbuilding and repair, glass, cement, and pesticides. All of these industries possess several of the characteristics noted above and also they have been identified by either the ASEAN or ECAFE (now ESCAP) secretariat for consideration as industries to be developed through some form of regional cooperation.

at all consumption points, the production costs at all production points and the transport costs between all production and consumption points. The number of intermediate consumption and production points depends on the number of stages in the production process. The model is a variant of the basic linear programing transportation problem. Instead of minimizing just transport costs, the objective of the model is to minimize both transport and production costs. Also, the plants to be distributed are characterized by economies of scale.[4] Therefore, in order to use a linear programing model, the concave, long-run total cost functions were approximated by piecewise linear functions. The model is static in the sense that no intertemporal optimization is attempted through the introduction of discounted flows, although demand projections are made. While the specification of the model in present value terms poses no particular difficulty, its empirical implementation, in particular, the large (prohibitive) number of computer iterations that would be required for its solution (see below), has made its adoption impracticable in the present case. However, as long as the relative importance of the consumption points and the relative costs of production in different locations do not change (or may be assumed to not change significantly) over the period in question, then the objective of minimizing costs in some forecast year, can be expected to yield the same results, in terms of plant locations, as when the objective is to minimize the present value of such costs distributed over time.[5]

The linearized programing model may be summarized as follows:
minimize

$$\sum_i A_i w_i + \sum_j B_j u_j + \sum_k C_k r_k + \cdots + \sum_m E_m s_m + \sum_i \sum_j c_{ij} x_{ij}$$
$$+ \sum_j \sum_k c_{jk} y_{jk} + \sum_k \sum_l c_{kl} v_{kl} + \cdots + \sum_m \sum_n c_{mn} z_{mn}\,, \qquad (1)$$

subject to

$$\sum_m \sum_n z_{mn} = \sum_n D_n\,, \qquad (2)$$

$$\sum_i \frac{x_{ij}}{a_{ij}} = \sum_k y_{jk}\,, \qquad \text{(over all } j\text{)}$$

$$\sum_j \frac{y_{jk}}{a_{jk}} = \sum_l v_{kl} \qquad \text{(over all } k\text{)}$$

$$\vdots \qquad \vdots$$

$$\sum_o \frac{q_{om}}{a_{om}} = \sum_n z_{mn}\,, \qquad \text{(over all } m\text{)} \qquad (3)$$

$$\sum_j x_{ij} \leq x^*_i\,,$$

$$\sum_k y_{jk} \leq y^*_j\,,$$

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[4] For the major works dealing with plant location and economies of scale, see [2, pp. 252–63] [6, pp. 643–66]. See especially [7, Appendix II] [18, pp. 136–58].

[5] The basic references for this type of model are [18, pp. 136–58] [4, pp. 620–53].

$$\begin{aligned}
&\sum_l v_{kl} \leq v^*_k \\
&\vdots \qquad \vdots \\
&\sum_n z_{mn} \leq z^*_m \,, && (4)
\end{aligned}$$

$$w_i, u_j, r_k, \cdots, s_m = 0 \text{ or } 1\,, \qquad (5)$$

$$\begin{aligned}
&\text{if } \quad w_i \genfrac{}{}{0pt}{}{=1,}{=0,} \quad \text{then} \quad \sum_j x_{ij} \genfrac{}{}{0pt}{}{\geq 0}{=0} \text{ for all } i\,, \\
&\text{if } \quad u_j \genfrac{}{}{0pt}{}{=1,}{=0,} \quad \text{then} \quad \sum_k y_{jk} \genfrac{}{}{0pt}{}{\geq 0}{=0} \text{ for all } j\,, \\
&\text{if } \quad r_k \genfrac{}{}{0pt}{}{=1,}{=0,} \quad \text{then} \quad \sum_l v_{kl} \genfrac{}{}{0pt}{}{\geq 0}{=0} \text{ for all } k\,, \\
&\qquad\quad \vdots \qquad\qquad\qquad \vdots \\
&\text{if } \quad s_m \genfrac{}{}{0pt}{}{=1,}{=0,} \quad \text{then} \quad \sum_n z_{mn} \genfrac{}{}{0pt}{}{\geq 0}{=0} \text{ for all } m\,, && (6)
\end{aligned}$$

$$x_{ij}, y_{jk}, v_{kl}\,, \cdots, z_{mn} \geq 0\,, \qquad (7)$$

where

A_i = annual fixed costs of a first stage plant at *i*.
B_j = annual fixed costs of a second stage plant at *j*.
C_k = annual fixed costs of a third stage plant at *k*.
$\vdots$
E_m = annual fixed costs of a final stage plant at *m*.
c_{ij} = annual per unit (ton) costs of production of a first stage plant at *i* plus the annual per unit (ton) costs of transport from plant *i* to plant *j*.
c_{jk} = annual per unit (ton) costs of production of a second stage plant at *j* plus the annual per unit (ton) costs of transport from plant *j* to plant *k*.
c_{kl} = annual per unit (ton) costs of production of a third stage plant at *k* plus the annual per unit (ton) costs of transport from plant *k* to plant *l*.
$\vdots$
c_{mn} = annual per unit (ton) costs of production of a final stage plant at *m* plus the annual per unit (ton) costs of transport from plant *m* to final consumption point *n*.
x_{ij} = quantity (tons) of annual output produced in the *i*th plant in the first stage and delivered to the *j*th plant in the second stage.
y_{jk} = quantity (tons) of annual output produced in the *j*th plant in the second stage and delivered to the *k*th plant in the third stage.
v_{kl} = quantity (tons) of annual output produced in the *k*th plant in the third stage and delivered to the *l*th plant in the fourth stage.
z_{mn} = quantity (tons) of annual output produced in the *m*th plant in the final stage and delivered to the *n*th final consumption point.

D_n = annual projected demand for the final stage product at the nth final consumption point.

a_{ij} = fixed input-output coefficient representing a linear relationship between the output of plant j in the second stage and the sum of the deliveries from plants in the first stage to plant j in the second stage.

a_{jk} = fixed input-output coefficient representing a linear relationship between the output of plant k in the third stage and the sum of the deliveries from plants in the second stage to plant k in the third stage.

$\vdots$

a_{om} = fixed input-output coefficient representing a linear relationship between output of plant m in the final stage and the sum of the deliveries from plants in the next-to-final stage to plant m in the final stage.

w_i = integer variable which can take the value of zero or one. If a plant does not exist at i, w_i equals zero.

u_j = integer variable (0 or 1).

r_k = integer variable (0 or 1).

$\vdots$

s_m = integer variable (0 or 1).

x^*_i = capacity output of plant i in the first stage.

y^*_j = capacity output of plant j in the second stage.

v^*_k = capacity output of plant k in the third stage.

$\vdots$

z^*_n = capacity output of n in the final stage.

Equation (1) is the objective function which minimizes the sum of both fixed and variable production and transport costs. The production and transport costs are exogenous and determined outside the model.[6] The fixed term accounts for the economies of scale and implies that marginal costs are below average costs over the range of output considered. Equation (2) represents the demand constraints. It states that the final demand at each final consumption point must be met exactly.[7] The quantities demanded at each final consumption point are

[6] Feedback effects with respect to transport costs (i.e., the impact of increasing traffic volumes on unit transport costs) have not been considered. Such costs usually arise from congestion represented by longer travel and/or waiting time. While this omission could be quite serious, if one were calculating the transport costs associated with the total volume of cargo to be moved on or through a particular facility, there does not appear to be any compelling reason to include such a relationship, which in any case would be difficult to measure, when dealing with only incremental traffic, which is a relatively small proportion of the total. It is implicitly assumed, therefore, that the traffic on particular facilities resulting from the establishment of new industries in the ASEAN region constitutes a sufficiently small proportion of the total traffic on those same facilities to permit one to ignore feedback effects.

[7] Inventories are assumed to be zero.

also determined outside the model.[8] The materials balance condition or technological relationship between production stages is represented by equation (3). It states that the sum of the deliveries to a given plant in a given stage from plants in the preceding stage divided by the input-output coefficient is equal to the output of that given plant. Equation (4) states that all plants have a capacity restriction. Therefore, economies of scale are realized for the entire range of output not exceeding the plant's capacity output.[9] These plant output restrictions are based on technological capacity or on available resource supplies depending on which constraint is met first. The technological constraint may be thought of as the upper limit on the output for a plant. However, due to critical shortages of skilled labor and capital at different locations, the attainable output level may fall short of the technological capacity of the plant.[10] Equation (5) simply defines the integer variable to have values of either zero or one. A zero means that there is no plant or production at a particular location and one means that there is. This is explained by equation (6). Equation (7) is the nonnegativity condition.

The skilled labor and capital constraints are key policy parameters in the model. Having determined the optimal (least cost) combination of plants, based on existing resource supplies at alternative locations, one may then relax resource constraints at particular locations to permit further realization of economies of scale and observe the impact on plant location and the total cost of meeting a given demand. The relaxation of resource constraints might be brought about by joint investments and the sharing of resources between member countries. Thus, the model can be used to determine the most efficient forms of joint country cooperation designed to overcome structural bottlenecks on the supply side.

The system of equations (1) through (7) may be rewritten as a mixed integer-continuous variable programing model. However, the computational experience with the Gomory cutting plane technique, which is used to solve this type of problem, has been disappointing. This is due to the fact that the number of iterations or cuts required to obtain the optimal solution is so large as to make solutions to practical problems unfeasible.[11] Therefore, the technique chosen to

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[8] To make the level of demand endogenous to the model, one must first establish a relationship between the demand for the commodity and its price and then relate the latter to the cost of supply which in turn depends on the locations of the plants. With this specification, the demand or size of the market is not independent of the locations of the plants. This relationship has not been included. Therefore, it is implicitly assumed that, at least within the range of prices which would correspond to the various alternative geographical combinations of plants to be considered, the price elasticity of the demand for the commodity in question is zero.

[9] Although the presence of a regional demand created by a regional complementation scheme may overcome the limitations imposed by a small national market, there is still the problem of supply bottlenecks (input shortages) to be met before there can be full realization of economies of scale.

[10] It is assumed that the supply of unskilled labor is available at every location in whatever quantities needed so that it may be ignored as a relevant constraint.

[11] For a discussion of integer-linear programing, see [5, Chap. 8].

solve the model is complete enumeration. This technique has the advantage of generating a total cost distribution for all the possible plant combinations. In the context of the problem considered (i.e., multi-national or regional industrial development), this additional information may be even more important than knowing only the optimal combination. It is likely that distributional considerations will prevent the optimal solution from being attained, in which case near optimal (or second and third best) solutions, which the complete enumeration method makes available, may be of more practical value to policy makers.

The complete enumeration method for solving a plant location problem for plants characterized by economies of scale has been used by Vietoriez, Manne, and Carnoy [18, pp. 136–57] [4, pp. 626–54]. First, a particular pattern of zeros and ones is assigned to the zero-one integer variables. For this particular pattern of zeros and ones, the remaining unknowns (x_{ij} through z_{mn}) are related by a constrained transshipment problem, the solution to which yields a local optimum. Variable costs are computed for this local optimum and added to the fixed costs associated with the particular pattern of zeros and ones assigned. This is done for all possible permutations of the zero-one integer variables. In general, if there are L potential plant locations, there are 2^L possible permutations of the zero-one integer variables. However, because the cost functions are approximated by piecewise linear functions, the number of linear programs to be solved is considerably larger due to the fact that for every geographical permutation of plants, there exist various combinations of fixed and variable costs depending upon which output interval for a plant is chosen. In general, this number is equal to

$$\sum_{x=1}^{L} \frac{L!}{x!(L-x)!} S^x , \tag{8}$$

where

L = number of possible plants.

x = number of plants (1's) in a particular permutation of possible plants.

$(L-x)$ = number of no plants (zeros) in a particular permutation of possible plants.

S = number of piecewise linear functions used to approximate concave total cost functions.

Thus, a serious drawback to the complete enumeration technique is that a great deal of computer time is required to solve all of the linear programs. For the industries chosen for this study, the problems to solve far exceeded any practical number even with the use of a high speed digital computer.[12] This problem was partially solved by using a short algorithm which quickly omitted the computation of all unfeasible linear programs. However, this still left too many feasible problems to solve. To reduce this number further to a manageable size, certain judgments were made concerning the maximum number of plants that could reasonably be expected in any stage of production. In this way, the

[12] The CDC 6600 was used.

very high cost feasible solutions were immediately eliminated. The final problem for the aluminum industry involved a total of 5,340 linear programs and took close to six hours to run.

However, in the case of the urea fertilizer industry, even with these adjustments, there were still too many linear programs to solve. This was because in addition to the new candidate locations for plants, the few existing plants in present locations were also tested.[13] The total number of locations or production points to be tested amounted to thirty-seven compared with only fifteen for the aluminum industry. The significance of the difference between these two numbers may be readily seen by inserting them in equation (8) above. Therefore, it did not prove practically feasible to enumerate or test all of the possible permutations of plants, 2^{37}. Instead, initially several possible permutations were selected and tested. On the basis of the results, which automatically precluded certain permutations and narrowed down the field of choice, other permutations were selected and tested. This process of selective iteration was repeated several times until a pattern emerged and it was possible to find, through trial and error, the least-cost, the near-best and several intermediate as well as some high-cost solutions.

IV. THE DISTRIBUTION MODEL

Each geographical combination of plants within the ASEAN region may entail actual, if not perceived, different distributions of benefits and costs between the countries. Therefore, the countries may be expected to respond differently to different proposed geographical combinations of plants. Combinations acceptable to one country may not be to the others. This might even lead to the threatened if not actual withdrawal of participation of some countries.[14] The problem essentially reduces to determining what weights should be assigned to the establishment of plants in particular locations in order to reflect distributional considerations, needed to preserve the stability of the arrangement. Of course, it is also possible for the countries to regard equity as a goal in and of itself rather than as an instrument for achieving stability. This, however, is more likely to be the case in a region comprised of countries at quite different levels of development, some of which may be so more advanced than the others, that concern for "distributional justice" may be the overriding consideration. The ASEAN region, however, does not appear to fit this description. Although a case could be made for claiming that Singapore should be motivated more by concern for its neighbors than by regional stability because it has a standard of living

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[13] In the case of most industries for possible development on a regional basis in the ASEAN region, there would be no existing plants in present locations to consider and, therefore, this problem would not normally arise as was the case for the aluminum industry. However, since urea is produced in the ASEAN region, although most of the region's requirements are met through imports, it was necessary to consider to what extent the present locations for plants and scales of operation, in addition to possible new plants, are optimal.

[14] The Pearson Commission calls attention to the need to eliminate those distributional effects which would threaten the long-run stability of the arrangement [9, p. 95].

well above the average for the region, one could also convincingly argue that since the major growth contributing factors of the past (entrepot trade and tourism) are not likely to grow at the same high rates in the future, Singapore's future growth will depend increasingly on its ability to produce a large proportion of the region's industrial output. Therefore, from the standpoint of developing an operational framework for examining the distributional problem in the context of industrial cooperation in the ASEAN region, it appears more reasonable to view the problem in terms of making adjustments in order to reduce the likelihood of some countries deciding to withdraw.

Let us begin by assuming that this distributional weight for any particular plant location is a function of both (1) the intensity of the reactions of the countries to the establishment of the plant in that location and also of (2) the importance which the region assigns to those reactions. The intensity of the reactions of the countries to the establishment of a plant in a particular location may be measured by changes in the regional market. For this formulation, it is assumed that the greater the positive difference between the welfare position of the country in which the plant is located and the welfare positions of each of the other countries, the more intense will be the reactions of the latter, which are assumed to be reflected by the actual or threatened withdrawal of participation and the consequent reduction in the size of the regional market.

Since the actual or potential change in the size of the regional market, due to the establishment of a plant at *i*, is the sum of the national markets in those countries which do, or threaten to, withdraw, we may write the following equation:

$$\Delta M_{ri}=\sum_{j=1}^{z} M_j\,, \tag{9}$$

where

ΔM_{ri} = the change in the size of the regional market from the establishment of a plant at i; and

M_j = the size of the national market in country j which threatens to withdraw because of the establishment of a plant at i.

Also, since actual or threatened withdrawal depends on the extent of the difference in welfare between the country in which the plant at *i* is located and the welfare positions of each of the other countries we may write the following functional relationship:

$$\sum_{j=1}^{z} M_j=f[(W_i-W_1),\cdots,(W_i-W_z)]\,, \tag{10}$$

where

W_i = the welfare position of the country in which the plant at i is located; and

$W_1,\ldots, W_z$ = the welfare positions of the other countries (1 through z) in the region.

To measure the importance that the region collectively assigns to the reactions of the countries to the establishment of a plant at i, we shall use the size of the national market in the country in which the plant is located relative to the size of the regional market. The reasoning behind this is that if a plant is located in a country which has a small proportion of the regional market, the other countries, because they represent a large proportion of the total market, have the capability to demand a different arrangement or withdraw and the withdrawal of large market countries can seriously threaten the stability, if not the feasibility, of a regionally integrated industry. Call this ratio M_i/M_r where M_i and M_r are the sizes of the national market in the country in which the plant at i is located, and the regional market, respectively.

The distributional weight which the region collectively assigns to the establishment of a plant at i (call it w_i) may be written as a product of both the intensity of the reactions of the countries and the importance of those reactions. Therefore:

$$w_i = \Delta M_{ri} \cdot \frac{M_i}{M_r}. \tag{11}$$

In order to express w_i as a positive distributional preference, we must take the reciprocal of the first term in equation (11). Thus,

$$w_i = \frac{M_i/M_r}{\Delta M_{ri}}. \tag{12}$$

V. EMPIRICAL IMPLEMENTATION

A. *The ASEAN Subregions*

The problem of plant location among the ASEAN countries involves determining not only the country but also the site within each country where the plants should be located. In order to identify the economic characteristics of the various potential general locations for plants within each of the five ASEAN countries, the latter have been divided into a total of twenty-seven subregions (see Figure 1), corresponding to the subregions in the *Southeast Asian Regional Transport Survey* [1].

For this study, the subregional breakdown in the *Regional Transport Survey* (RTS) is adequate. A more detailed breakdown for this analysis would not be warranted given the fact that within these subregions there is not much variation in the factors which affect industrial location. The one exception might be the Philippines where national planners have divided the country into eleven zones as compared with six in this study.[15] A closer examination, therefore, might be warranted for the Philippines if the solution to the model, locates plants in subregions within the Philippines which are judged to have diverse industrial location

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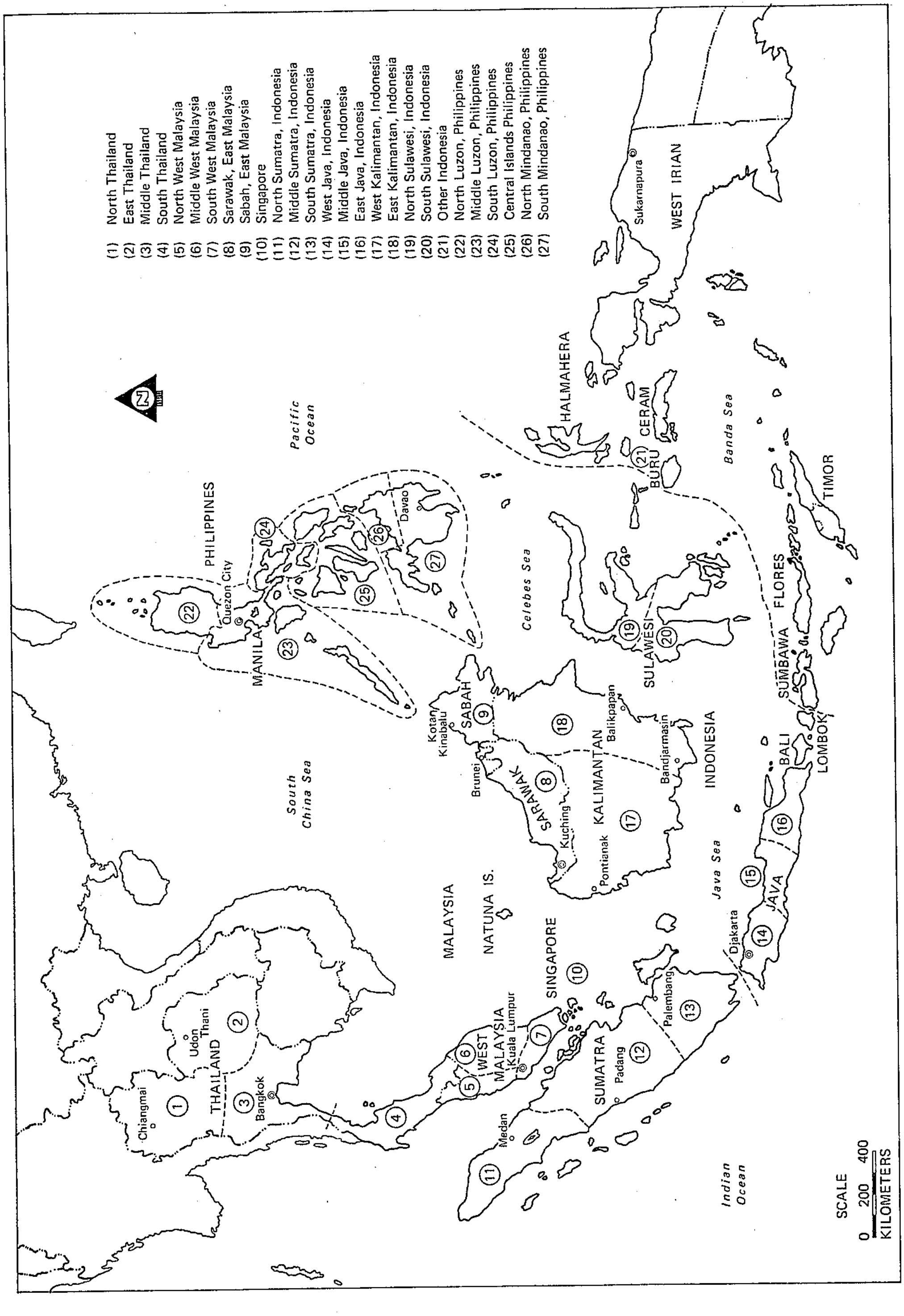
[15] The Visayan or Central Island area in this study (subregion 25) is comprised of three regions (Western, Central, and Eastern Visayas). Southern Luzon (subregion 24) is comprised of two regions (Southern Tagalog and Bicol) and Southern Mindanao (subregion 27) is comprised of two regions (Western and Southern Mindanao).

Fig. 1 ASEAN Subregions



characteristics. For the other countries, the breakdown in subregions corresponds, more or less, and, in the case of Thailand, exactly to the breakdown used by national planners.

B. *Production and Transport Costs*

Aluminum production may be divided into four stages—bauxite mining, alumina production, aluminum reduction, and aluminum fabrication. Because fabrication plants, which are generally small, do not require regional markets and capital sharing schemes in order to be feasible, they do not offer much opportunity for regional cooperation. In fact, fabrication plants already exist in all of the ASEAN countries. Therefore, for the purposes of this study, aluminum fabrication is treated as final demand and production refers to the outputs of the three preceding stages.

The production of urea fertilizer may be divided into three stages: raw material feedstock extraction, ammonia production, and urea production. For the purposes of this study, it has been assumed that a regionally integrated urea fertilizer industry in the ASEAN region would be based on gaseous and liquid hydrocarbon (naphtha) feedstocks. This is because the ASEAN region is particularly well endowed with natural gas and petroleum resources (mainly Indonesia), the transport costs associated with the handling of these materials is lower than what it is for solid feedstocks, and also because the capital and labor costs are lower in ammonia plants designed for gaseous and liquid hydrocarbon feedstocks.

Production costs in the various stages of production in the aluminum and urea fertilizer industries were derived from production function data.[16] These production functions exhibit the common characteristics of being linear with respect to all utilities and raw and processed materials and exponential (concave) with respect to the labor and capital inputs. The latter relationship represents economies of scale. The same production functions were used for all plants in the same stage regardless of location. This was based on the following assumptions: (1) all plants in the same stage adopt the same technological process; (2) agglomeration economies are exclusively pecuniary in nature and are, therefore, reflected in input prices; and (3) skilled labor, unskilled labor, raw and processed materials, and capital are homogeneous categories. Finally, to obtain production costs (annual cost per unit of output) the quantities given by the various production functions were multiplied by the respective input prices which were estimated independently in each of the ASEAN subregions. In order to use the linear programing model, the long-run total cost functions were approximated by piecewise linear functions.

Truck rail, port, and ocean shipping transport costs were derived for the ASEAN region's transport facilities and vehicles. The cost of pipeline transport of natural gas, required for the urea fertilizer industry, was also estimated. In estimating these transport costs, the route chosen between any two points consisted of the minimum cost means by which to transport the cargo in question.

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[16] The principal sources were [12] [10] [15] [11] [3] [16] [17] [8] [14, No. 1].

Whether a particular route is actually used and to what extent, depends, of course, on the solution to the overall linear programing model.

C. *The Market*

Forecasts of the markets for aluminum and urea fertilizer in 1980 were made for each of the ASEAN subregions. The method used for estimating the future demand for aluminum consisted of first estimating the demand in each of the ASEAN countries by use of regression analysis and then distributing the national aggregates among the subregions within each country in proportion to each subregion's forecast population. In order to ensure that this method of distribution would not lead to unreasonable results such as the projection of a demand for aluminum ingot in a primarily agricultural and sparsely populated subregion in which there would be little or no likelihood of the establishment of a metal fabricating industry, only those subregions with at least one large population center (250,000 or more) were used. Of the twenty-seven subregions, sixteen were estimated to fulfill this condition by 1980.

The demand for urea fertilizer in each of the twenty-seven ASEAN subregions was estimated directly from forecasts of crop production, the percentage of each crop produced with urea and the dosage of urea applied in each of the ASEAN subregions. For this purpose government officers from the respective agricultural departments in each country were consulted and requested to furnish their own forecasts for the variables based on their first-hand knowledge of the government's agricultural extension plans, the soil and climatic conditions in each subregion, the likely presence and quantity of other agricultural inputs in the subregion in 1980, and their perception of the farmers' inclination to use chemical fertilizer.

D. *Plant Output Constraints*

Plant output constraints are a function of either technology, skilled labor or capital depending on which constraint is met first. To estimate the constraint imposed by technology, the largest plant found in the world was used. Because the supply functions for skilled labor and capital (mainly industrial capital which has to be imported) cannot be estimated at the level of precision required to determine the exact amount of skilled labor and capital that would be available for a specific enterprise in a particular subregion, a qualitative approach was adopted. Subregions were classified according to whether they will continue through at least 1975 to be poorly, moderately or sufficiently endowed with skilled labor and capital resources.

The following criteria were used to categorize the ASEAN subregions.

	Skilled Labor	Capital
Poor	$\frac{W_{sr}-W_{cc}}{W_{cc}}>0.20$	$DSR\geq 5.0$
Moderate	$0.20\geq\frac{W_{sr}-W_{cc}}{W_{cc}}>0.10$	$5.0>DSR\geq 2.5$
Sufficient	$0.10\geq\frac{W_{sr}-W_{cc}}{W_{cc}}$	$DSR\leq 1.0$

W_{sr} =wage rate for skilled labor in a particular subregion.
W_{cc} =wage rate for skilled labor in the country's capital city.
DSR=official debt service ratio for the country defined as the ratio of official debts outstanding plus service charges to foreign exchange reserves.

"$W_{sr}-W_{cc}$" is the premium, used here as an index of relative scarcity, that is paid to attract skilled laborers from, or to reduce their incentive to go to, the capital city, where it is assumed the supply of skilled labor is sufficient. This measure, of course, assumes that there are no skilled labor productivity differences between subregions. However, even if there are differences, it is unlikely that they would be sufficiently large to alter the ranking of subregions according to the broad classifications adopted.

The debt service ratio (DSR) is used as an index of the availability of funds for imported industrial capital goods. Because the availability of funds on a subregional level is essentially dependent on a country's regional (subnational) development policy, all of the subregions within a particular country have been assumed to have a potentially equal chance of receiving imported capital. Therefore, the subregions within a country were assigned the same ranking as that for the country as a whole.

Subregions classified as poor, moderate or sufficient with respect to capital and skilled labor were then assumed to have plants which operate in the first, second or third output range, respectively. These ranges correspond to the piecewise linear approximations of the cost functions.

E. *Candidate Locations to Be Tested*

The plant locations or production points to be tested in the model must be initially specified. The locations of plants in the first stage of production in both industries (i.e., bauxite mines for the aluminum industry and oil refineries and natural gas deposits for the urea fertilizer industry) and the locations of the few existing ammonia and urea fertilizer plants in the ASEAN countries, are already known. To these one must add the new candidate locations for plants to be tested in the model. These new candidate locations consisted of those which are frequently mentioned as possibilities and those which have *prima facie* plausibility as suggested by a cursory review of the cost characteristics of each potential location. The total list of candidate locations that were tested is presented in Table I.

F. *Distributional Weights*

In order to use the distribution model, the general form of equation (12) must first be converted into a specific form which can be empirically estimated. To do this, it is assumed that the relative welfare of a country (W_i, $W_1 \ldots$, W_z) can be measured by per capita GDP. It is further assumed that all countries with a per capita GDP which is more than 20 per cent less than the country in which the plant at i is located, would, at least, threaten withdrawal of participation if it is suggested that the plant be established at location i. With these assumptions,

TABLE I
CANDIDATE PRODUCTION POINTS

The Aluminum Industry	The Urea Fertilizer Industry
Stage I Bauxite: Johore, West Malaysia (subregion 7) and the Indonesian islands of the Riau Archipelago, mainly Bintan (subregion 12).	Stage I Feedstock: Naphtha: Oil refineries at Si Racha, Middle Thailand (subregion 3); Port Dickson, West Malaysia (subregion 7); Sarawak, East Malaysia (subregion 8); Singapore (subregion 10); Dumai, Central Sumatra (subregion 12); Palembang, South Sumatra (subregion 13); Wonokrono, East Java (subregion 16); Balikpapan, East Kalimantan (subregion 18); and Bataan and Batangas, Middle Luzon (subregion 23). Natural Gas: North Sumatra (subregion 11); Middle Sumatra (subregion 12); South Sumatra (subregion 13); and East Java (subregion 16).
Stage II Alumina: Thailand (subregion 3); Johore Bahru, West Malaysia (subregion 7); Kuching, East Malaysia (subregion 8); Singapore (subregion 10); Kuala Tanjung in North Sumatra, Indonesia (subregion 11); and Pontianak in West Kalimantan, Indonesia (subregion 17).	Stage II Ammonia: Existing plants at Mae Moh, North Thailand (subregion 1); Port Dickson, West Malaysia (subregion 7); Palembang, South Sumatra (subregion 13); Gresik, West Java (subregion 14); Cebu, Central Islands, Philippines (subregion 25); and Iligan, North Mindanao, Philippines (subregion 26) and other candidate ammonia plants at ammonia plant locations included: Sattahip, Thailand (subregion 3); Port Dickson, West Malaysia (subregion 7); Miri in Northern Sarawak, East Malaysia (subregion 8); Singapore (subregion 10); Surabaya in East Java, Indonesia (subregion 16); Batangas in Middle Luzon, Philippines (subregion 23); and Ormoc on Leyte in the Visayan region, Philippines (subregion 25).
Stage III Aluminum: All of the above plus Legaspi in Southern Luzon, Philippines (subregion 24), and Iligan in Northern Mindanao, Philippines (subregion 26).	Stage III Prilled Urea: Existing plants at Mae Moh, North Thailand (subregion 1); Palembang, South Sumatra (subregion 13); Gresik, West Java (subregion 14); and Bataan, Middle Luzon (subregion 23); plus the new candidate plants which included all of the sites mentioned under ammonia above as well as Kuantan; Middle, West Malaysia (subregion 6).

the weights for each country can be derived for the industries considered (Table II).

For example, from this index one may conclude that in the aluminum industry, the region collectively assigns a little less than twice as much value to the establishment of a plant in Thailand than it does to one in Singapore or, to use another

TABLE II
WEIGHT VALUES FOR EACH ASEAN COUNTRY

Industry / Country	Aluminum	Urea Fertilizer
Thailand	6.26	5.62
Malaysia	1.08	0.40
Singapore	3.25	0.10
Indonesia	8.34	16.54
Philippines	5.21	3.01

example, that in the urea fertilizer industry the region collectively assigns seven and one half times as much value to the establishment of a plant in the Philippines than it does to one in Malaysia. For both industries, Indonesia is estimated to have the highest distributional weight which is not surprising in view of its relatively low per capita income and its relatively large share of the regional market in both industries.

VI. THE RESULTS

The results are presented in three forms: (1) with plant output constraints, (2) without plant output constraints other than that imposed by the state of technology, and (3) adjusted for distributional considerations.

A. *With Plant Output Constraints*

1. *The regionally integrated aluminum industry*

The plant locations which comprise the optimal (least cost) solution for a regionally integrated aluminum industry in the ASEAN region include: (a) bauxite mines in Johore, West Malaysia (subregion 7) and on the Indonesian islands of the Riau Archipelago, mainly Bintan (subregion 12); (b) one alumina plant in Johore, West Malaysia (subregion 7); and (c) three aluminum plants including one at Sattahip, Thailand (subregion 3), one at Kuala Tanjung in North Sumatra, Indonesia (subregion 11) and one in Iligan in Northern Mindanao, Philippines (subregion 26).

The quantities, x_{ij}, $y_{jk}, \ldots, z_{mn}$, to be shipped between the various production and consumption points as well as the annual output of each plant in the solution are shown in Table III. The total annual cost to the ASEAN region of establishing the regionally integrated aluminum industry works out to U.S.$50.85 million. The average cost per ton of aluminum metal is U.S.$366.7. This compares most favorably with the average F.O.B. import price of aluminum in the ASEAN countries of U.S.$741 per ton as of June 1973. Thus, even from a static allocative efficiency point of view, the decision to substitute the production of aluminum on a regional scale for extra-regional imports, is well justified. The savings per ton in 1980 is U.S.$374. Total annual regional savings from the establishment of the regionally integrated aluminum industry is U.S.$51.85 million or U.S.$374.3 per ton of aluminum metal which is distributed among the countries as follows: Singapore, U.S.$16.15 million; Indonesia, U.S.$12.54 million; Thailand, U.S.$10.76 million; Philippines, U.S.$7.96 million; and Malaysia, U.S.$4.44 million. The least-cost solution entails the concentration of alumina production in one location in Johore next to the bauxite mine there and relatively close (via the Malacca Straits) to the mines on the islands in the Riau Archipelago, thereby capitalizing on the economies of scale associated with production in the state of Johore in Southern West Malaysia and, at the same time, avoiding the high cost of transporting bauxite long distances within the region.

The three aluminum plants included in the optimum solution are widely distributed throughout the region. In this case, proximity to markets and low production costs (in particular, power costs) emerge as the most significant factors in determining the location of the plants. The largest aluminum plant, producing 78,650 tons of aluminum metal per annum, is centrally located in Sattahip where a major deep sea port already exists. This aluminum plant serves more than half (56 per cent) of the regional market including Thailand, Malaysia, Singapore, and most of Indonesia excluding Kalimantan and Sulawesi. The aluminum plant in Kuala Tanjung in Northern Sumatra is close to a cheap hydro power source on the Asahan River. However, its scale is relatively small (30,000 tons per annum) which is largely explained by the capital resource constraint at that location. This plant serves the largest single market in the ASEAN region (63 per cent of Singapore's total requirement) plus the island of Sumatra. The other aluminum plant in Iligan in Northern Mindanao, is of the same scale as the plant in Kuala Tanjung (30,000 tons per annum) and serves all of the Philippines plus East Java, Kalimantan, and Sulawesi. Iligan is also close to a cheap hydro power source on the Agus River. It is interesting to note that under present conditions, the least-cost solution does not involve a single location at which all three stages of production are fully integrated.

The second best solution differs from the first in that one of the aluminum plants is located in Kuching, East Malaysia (subregion 8) instead of in Kuala Tanjung (subregion 11). The total annual cost to the region of adopting this solution is U.S.$51.18 million which is U.S.$2.38 per ton of aluminum metal more than the least-cost solution. The third and fourth best solutions also involve a single change in the location of one of the aluminum plants; from Iligan (subregion 26) to Legaspi (subregion 24) and from Iligan (subregion 26) to Kuching (subregion 8), respectively. The total additional cost per ton of aluminum metal of adopting the third and fourth best solutions instead of the least-cost solution, works out to U.S.$2.89 and U.S.$3.45, respectively.

2. *The regionally integrated urea fertilizer industry*

For the regionally integrated urea fertilizer industry, the optimum locations for plants or production points in the ASEAN region include: (a) natural gas fields in two locations in Indonesia: South Sumatra (subregion 13) and Djati Barang, East Java (subregion 16); (b) existing refineries in two general locations: in the vicinity of Sattahip, Middle Thailand (subregion 3) and in Bataan and

Batangas in Middle Luzon, Philippines (subregion 23); (c) six ammonia plants including three existing ones in Palembang, South Sumatra, Indonesia (subregion 13), Cebu in the Visayan region, Philippines (subregion 25) and in Iligan in North Mindanao, Philippines (subregion 26), and three new ammonia plants in Sattahip, Thailand (subregion 3), Surabaya, East Java, Indonesia (subregion 16) and in Batangas, Middle Luzon, Philippines (subregion 23); and (d) six urea fertilizer plants including two existing ones in Palembang, South Sumatra, Indonesia (subregion 13) and in Gresik, West Java, Indonesia (subregion 14) and four new urea plants in Sattahip, Thailand (subregion 3), Surabaya, East Java, Indonesia (subregion 16), Batangas, Middle Luzon, Philippines (subregion 23), and in Ormoc on Leyte in the Visayan region, Philippines (subregion 25).

The quantities to be shipped between the various production and consumption points as well as the annual output of each plant in the solution are shown in Table IV. The total annual cost to the ASEAN region of establishing the regionally integrated urea fertilizer industry works out to U.S.$26.36 million or U.S.$25.07 per ton of urea produced. The average F.O.B. import price of bagged prilled urea in the ASEAN region is U.S.$110 (June 1972). Thus, the gain from import substitution on a regional scale is quite substantial. Total annual regional savings from the establishment of a regionally integrated urea fertilizer industry work out to U.S.$89.26 million or U.S.$84.93 per ton to urea. These annual savings are distributed among the ASEAN countries as follows: Indonesia, U.S.$48.33 million; Thailand, U.S.$28.23 million; Philippines, U.S.$9.38 million; Malaysia, U.S.$3.32 million.

In the least-cost solution, the production of feedstock is about as widely distributed throughout the ASEAN region as is physically possible. Large natural gas deposits are found only in Indonesia, and the solution contains two production points; one in South Sumatra (subregion 13) and the other all the way on the other end of Java (subregion 16). Similarly, naphtha, in the solution, is produced in two locations which are fairly widely separated; at the refineries in the vicinity of Sattahip, Thailand (subregion 3) and also at the refineries in Batangas in Middle Luzon, Philippines (subregion 23). Taken together, these locations for feedstock production generally define the outer boundaries of the ASEAN region.

The ammonia plants in the solution are clearly concentrated in the vicinity of the feedstock production points. All three new ammonia plants are located either close to or at the site of the feedstock. The new ammonia plant, based on naphtha feedstock, at Sattahip, Thailand (subregion 3) is fed from the nearby refineries at Si Racha and from those in the Bangkok area, a short distance by road to the north. The new ammonia plant at Surabaya in East Java (subregion 16) is connected to the presently untapped gas fields at Djati Barang by pipeline, some 120 kilometers to the south. The cost of building this pipeline has been taken into account in the solution. The new ammonia plant in Batangas in Middle Luzon, Philippines (subregion 23) is located at the main site for oil refineries in the Philippines.

It would appear that transportation factors have played a large role in selecting

TABLE III

ANNUAL QUANTITIES IN THE SOLUTION FOR THE REGIONALLY INTEGRATED ALUMINUM INDUSTRY WITH PLANT OUTPUT CONSTRAINTS

Stage I (Tons)

Bauxite Plants	Alumina Plants	Total Bauxite Production by Plant
	Subregion 7	
Subregion 7	432,330	432,330
12	150,000	150,000

Stage II

Alumina Plants	Aluminum Plants			Total Alumina Production by Plant
	Subregion 3	11	26	
Subregion 7	157,300	60,000	60,000	277,300

Stage III

Aluminum Plants	Consumption Points																Total Aluminum Production by Plant
	Subregion 1	2	3	5	7	10	11	13	14	15	16	18	20	23	25	27	
Subregion 3	7,218	10,375	11,177	5,691	6,189	15,877		1,982	8,167	8,197	3,777						78,650
11						27,303	2,697										30,000
26											5,611	1,033	2,076	9,910	6,554	4,816	30,000
Total consumption	7,218	10,375	11,177	5,691	6,189	43,180	2,697	1,982	8,167	8,197	9,388	1,033	2,076	9,910	6,554	4,816	138,650

TABLE IV

Annual Quantities in the Solution for the Regionally Integrated Urea Fertilizer Industry with Plant Output Constraints

Stage I

Feedstock Production		Ammonia Plants						Total Feedstock Production by Plant
		Subregion 13	25	26	3	16	23	
Natural gas	Subregion 13	6,379.42						6,379.42
	16					4,522.00		4,522.00
Naphtha	3				47,888.00			47,888.00
	23		73,800.00	102,500			12,789.05	189,089.05

Stage II

Ammonia Plants	Urea Plants						Total Ammonia Production by Plant
	Subregion 13	14	3	10	16	23	
Subregion 13*	86,130.00	37,700.00		63,800.00			187,630.00
25*						90,000.00	90,000.00
26*					87,400.00	37,600.00	125,000.00
3			58,400.00				58,400.00
16			133,000.00				133,000.00
23					123,752.67		123,752.67

TABLE IV (Continued)

Stage III

Urea Plants	Consumption Points Subregion 1	2	3	4	5	6	7	8	9	11	12	13	14
Subregion 13*										44,110	14,460	40,050	49,880
14*													65,000
3	7,640	54,640	176,750	90,970									
16													
23				2,420	29,190	5,460	3,660	220	550		15,680		
25													
Total consumption	7,640	54,640	176,750	93,390	29,190	5,460	3,660	220	550	44,110	30,140	40,050	114,880

Urea Plants	Consumption Points Subregion 15	16	17	18	19	20	21	22	23	24	25	26	27	Total Urea Production by Plant
Subregion 13*														148,500
14*														65,000
3														330,000
16	100,300	9,700												110,000
23		66,750	6,110					9,080	38,460					177,580
25		99,600		7,150	10,430	31,710	8,160			8,930	33,640	2,340	18,040	220,000
Total consumption	100,300	176,050	6,110	7,150	10,430	31,710	8,160	9,080	38,460	8,930	33,640	2,340	18,040	1,051,080

Note: All units expressed in tons except for natural gas which is in terms of million standard cubic feet.
* An existing plant.

this particular solution as one would have expected since it is during the stage of ammonia synthesis that the feedstock undergoes a considerable reduction in weight. Consequently, it is often advantageous, as it apparently is in this case, to eliminate raw material transportation costs by locating the ammonia plant at or close to the source of the feedstock. Water, which is needed in abundant supply for processing and cooling in the ammonia plant, does not appear to have had a significant effect on plant location due to the general uniformity of these costs throughout most of the region; although one of the new ammonia plants is located in Surabaya (subregion 16) where, like on most of Java, there are large natural reservoirs of underground water which makes its management easier, hence, its potential operating costs lower than in most other locations in the region.

The urea plants in the least-cost solution are located fairly close to the sites for ammonia plants. However, at the same time, these plants are in close proximity to the largest markets in the region. What one finds is a situation where closeness to inputs and to markets are two forces which, in this instance, are pulling in the same direction. Three of the four new urea plants, namely those in subregions 3, 16, and 23 are at the sites of ammonia plants. These subregions alone also account for about 37 per cent of the total regional market.

In the solution, the existing urea plant complex (Pusri) in Palembang, South Sumatra (subregion 13) serves a large portion of the Indonesian market just as it does at present. This plant, in the least-cost solution, serves all of Sumatra (subregions 11, 12, and 13) plus a portion of the market in West Java (subregion 14). The existing urea plant at Gresik in West Java (subregion 14), which is also included in the least-cost solution, serves only the West Java area. The new plant at Sattahip serves all of Thailand except for a small area in the south. This gives the Sattahip plant the distinction of having the largest market (31 per cent of the total). The new plant in Surabaya, East Java (subregion 16) serves only the Middle and East Java markets. The two new urea plants in the Philippines serve the widest geographical area: the Batangas plant (subregion 23) serves North and Middle Luzon (subregions 22 and 23) in the Philippines as well as all of Malaysia (subregions 5, 6, and 7), East Java (subregion 16), and West Kalimantan (subregion 17); the new plant in Ormoc on Leyte in the Visayan region (subregion 25) serves, in addition to the markets in the southern parts of the Philippines (subregions 24, 25, 26, and 27), East Kalimantan (subregion 18) and Sulawesi (subregions 19 and 20) as well.

It is interesting to note that among the six existing ammonia plants in subregions 1, 7, 13, 14, 25, and 26, only those in subregions 13, 25, and 26 are included in the least-cost solution. The others, in subregions 1, 7, and 14 are not required for the regionally integrated urea fertilizer industry and efficiency considerations would have them serve other needs. However, the existing urea plants, excluded from the least-cost solution, would not have any alternative uses and, according to the solution, should be closed. These are the urea plants at Mae Moh in North Thailand (subregion 1) and in Bataan, Philippines (subregion 23). The ammonia-urea complex at Mae Moh, in particular, is very costly to operate as it is based on a lignite feedstock. Also, the scale of operation is quite small and its location is fairly remote. The establishment of an integrated urea fertilizer industry in the ASEAN region would make its existence even less defensible than it already is.

The second best solution to the problem entails one small change which substitutes stepped-up production of natural gas in South Sumatra (subregion 13) for the production of natural gas in the presently untapped fields in East Java (subregion 16). While this involves a slightly higher cost than the first solution, the difference is negligible and for all practical purposes, other things being equal, one should probably be indifferent between the two. The third best solution also eliminates the production of natural gas in East Java (subregion 16) as well as the production of naphtha at the refineries in the vicinity of Sattahip. To meet the necessary raw material requirements, the third best solution includes naphtha production in two new locations, Singapore (subregion 10) and Dumai in Middle Sumatra (subregion 12). There are no other differences in plant location between this solution and the best one. The difference in total annual cost is again fairly small, approximately U.S.$0.101 million.

The fourth best solution does introduce some fairly significant differences in plant location. As in the third best solution, the production of natural gas in subregion 16 and the production of naphtha in subregion 3 are excluded. The corresponding reduction in raw material output is met through the production of more natural gas in subregion 13 and naphtha production at the refineries in Singapore (subregion 10). However, the fourth best solution also excludes the ammonia plant in Batangas, Middle Luzon, Philippines (subregion 23) and includes an ammonia-urea complex in Singapore. This solution is about U.S.$0.42 million per annum more costly than the least-cost solution.

B. *Without Plant Output Constraints*

The capital and skilled labor constraints affect the solution through their impact on the output or capacity constraints of each candidate plant. They, therefore, limit the extent to which potential economies of scale may be realized. However, because labor can be trained and/or recruited from other subregions or even from neighboring countries and capital requirements can be met through pooling or borrowing arrangements, such constraints serve more to indicate the degree and kind of regional cooperation that is needed than they do to represent the limitations imposed by the supply of available resources. In fact, it was precisely for this reason, i.e., to determine what type and how much cooperation would be needed, that the model was initially empirically implemented using capital and skilled labor constraints. The results from removing these constraints at each plant site are discussed below.

1. *The regionally integrated aluminum industry*

The main effect from removing the plant output constraints for the candidate plants in the aluminum industry, namely, skilled labor in subregions 8 and 17 and capital in subregions 11, 17, 24, and 26, is that the optimum location for the alumina plant shifts from Southern Johore (subregion 7) to the selected site of one of the aluminum smelters, Kuala Tanjung, near the Asahan River in North Sumatra (subregion 11). All other production points including the two mine sites (subregions 7 and 12) and the three aluminum plant sites (subregions 3, 11, and 26), remain the same. The quantities to be shipped between the various production and consumption points and the annual output of each plant in this solution are shown in Table V.

Whereas the solution to the first problem (with plant output constraints) had alumina production integrated with bauxite mining in subregion 7, the present solution involves the integration of alumina with aluminum production in Kuala Tanjung in subregion 11. Furthermore, with the integration of alumina and aluminum production in Kuala Tanjung, the optimum scale of the aluminum plant at that location has increased from 30,000 tons per annum to 78,650 tons. This effectively makes the aluminum smelter in Kuala Tanjung the largest of the three aluminum plants in the solution in comparison to the first solution in which the smelter in Sattahip (subregion 3) held this distinction. Correspondingly, in the present solution, the aluminum smelter in Kuala Tanjung serves the largest market (56 per cent) including Malaysia, Singapore, and Indonesia excluding the islands of Kalimantan and Sulawesi which remain within the market area of the aluminum smelter in Iligan in Northern Mindanao (subregion 27). Thus, even though the present solution entails the shipment of bauxite from two locations to one, instead of from only one location as in the first solution, it is still more economical to adopt the present solution due mainly to the elimination of one transport path (i.e., from the alumina plant in subregion 7 to the aluminum plant in subregion 11) and also to the economies which accrue from building a large aluminum plant close to an abundant potential source of cheap hydroelectric power.

The total annual cost to the ASEAN region of implementing the present solution works out to U.S.$48.61 million or U.S.$350 per ton of aluminum metal. Compared with the average F.O.B. import price of aluminum in the ASEAN region the savings from establishing a regionally integrated aluminum industry in accordance with the present solution amounts to U.S.$391. This is a savings of U.S.$17 per ton more than what would be achieved by implementing the solution to the first problem which included plant output constraints imposed by the supply of available resources in different locations. It clearly shows the large potential gains for the region that could be derived from removing these constraints, in particular, the capital constraint in subregion 11 in Indonesia.

2. *The regionally integrated urea fertilizer industry*

For the regionally integrated urea fertilizer industry, the removal of plant output constraints, namely, skilled labor in subregions 6 and 8 and capital in subregions 16, 23, and 25, has the general effect of increasing the scale of operation at particular locations and reducing the total number of production points. The quantities to be shipped between the various production and consumption points and the scale of each plant are shown in Table VI. The optimal

TABLE V

ANNUAL QUANTITIES IN THE SOLUTION FOR THE REGIONALLY INTEGRATED ALUMINUM INDUSTRY WITHOUT PLANT OUTPUT CONSTRAINTS

Stage I (Tons)

Bauxite Plants	Alumina Plants	Total Bauxite Production by Plant
	Subregion 11	
Subregion 7	150,000	150,000
12	432,330	432,330

Stage II

Alumina Plants	Aluminum Plants			Total Alumina Production by Plant
	Subregion 3	11	26	
Subregion 11	60,000	157,300	60,000	277,300

Stage III

Aluminum Plants	Consumption Points																Total Aluminum Production by Plant
	Subregion 1	2	3	5	7	10	11	13	14	15	16	18	20	23	25	27	
Subregion 3	7,218	10,375	11,177						1,230								30,000
11				5,691	6,189	43,180	2,697	1,982	6,937	8,197	3,777						78,650
26											5,611	1,033	2,076	9,910	6,554	4,816	30,000
Total consumption	7,218	10,375	11,177	5,691	6,189	43,180	2,697	1,982	8,167	8,197	9,388	1,033	2,076	9,910	6,554	4,816	138,650

TABLE VI

Annual Quantities in the Solution for the Regionally Integrated Urea Fertilizer Industry without Plant Output Constraints

Stage I

Feedstock Production		Ammonia Plants		Total Feedstock Production by Plant
		Subregion 13	16	
Natural gas	Subregion 13	7,127.30	2,600.00	9,727.30
	16		11,000.00	11,000.00

Stage II

Ammonia Plants	Urea Plants						Total Ammonia Production by Plant
	Subregion 13	14	3	10	16	23	
Subregion 13*	86,130.00	37,700.00			85,796.40		209,626.40
16			191,400.00	36,261.60	97,153.00	75,185.40	400,000.00

TABLE VI (Continued)

Stage III

Urea Plants	Consumption Points Subregion 1	2	3	4	5	6	7	8	9	11	12	13	14
Subregion 13*										22,320	30,140	40,050	49,880
14*													65,000
3	7,640	54,640	176,750	90,970									
10				2,420	29,190	5,460	3,660			21,790			
16								220					
23									550				
Total consumption	7,640	54,640	176,750	93,390	29,190	5,460	3,660	220	550	44,110	30,140	40,050	114,880

Urea Plants	Consumption Points Subregion 15	16	17	18	19	20	21	22	23	24	25	26	27	Total Urea Production by Plant
Subregion 13*			6,110											148,500
14*														65,000
3														330,000
10														62,520
16	100,300	176,050		7,150		31,710								315,430
23					10,430		8,160	9,080	38,460	8,930	33,640	2,340	18,040	129,630
Total consumption	100,300	176,050	6,110	7,150	10,430	31,710	8,160	9,080	38,460	8,930	33,640	2,340	18,040	1,051,080

Note: All units expressed in tons except for natural gas which is in terms of million standard cubic feet.

* An existing plant.

locations are summarized: (1) natural gas in South Sumatra (subregion 13) and in Djati Barang, East Java (subregion 16); (2) two ammonia plants including the existing plant at the Pusri complex in Palembang, South Sumatra (subregion 13) and a new plant in Surabaya, East Java (subregion 16); and (3) six urea fertilizer plants including two existing plants in Palembang, South Sumatra (subregion 13) and in Gresik, West Java (subregion 14) and four new urea plants in Sattahip, Thailand (subregion 3), Surabaya, East Java (subregion 16), Batangas, Middle Luzon (subregion 23) and in Ormoc on Leyte in the Visayan region (subregion 25).

In the first stage of feedstock production, two production points have been eliminated. These are the naphtha production points at the refineries in the vicinity of Sattahip, Thailand (subregion 3) and in Batangas, Middle Luzon (subregion 23). This leaves only natural gas, in subregions 13 and 16 in Indonesia, as a feedstock for the regionally integrated urea fertilizer industry. The scale of production is approximately the same at both sites.

The ammonia plants in the least-cost solution, without plant output constraints, are restricted to two locations instead of six, as in the first case, and these are in the vicinity of the two natural gas production points in subregions 13 and 16. The plant at Palembang, South Sumatra (subregion 13) is part of the existing Pusri complex there. Thus, the only new ammonia plant included in the present solution is the one in Surabaya, East Java (subregion 16). Its annual capacity is 400,000 tons which is about three times larger than in the solution which included plant output constraints. As a result of obtaining this scale, the unit (ton) cost of production is reduced from U.S.$8.21 to U.S.$5.51, a fairly significant economy. The new plant in subregion 16 is fed partially by pipeline from the presently untapped gas fields to the south and also by LPG tanker from the fields in South Sumatra (subregion 13), where the largest reserves are found. Existing port facilities at both Palembang and Surabaya are quite adequate to handle this trade.

In the third stage of urea fertilizer production, the solution without plant output constraints contains only one change in plant location. The urea plant at Ormoc on Leyte in the Visayan region of the Philippines (subregion 25) is replaced by an urea plant in Singapore (subregion 10). With the removal of the plant output constraints, specifically the capital constraints in subregions 16 and 23, the urea plant in Sattahip is no longer the largest plant in the solution. This distinction is now shared by both the Sattahip and Surabaya plants. Each has an annual capacity of some 330,000 tons.

It may be noted that the present solution contains fewer ammonia plants but the same number of urea fertilizer plants as in the solution which included plant output constraints. The effect of this change is essentially to increase the distances (mostly over water) that ammonia has to be transported within the region. The principal movements in this connection are between the ammonia plant in Surabaya, East Java (subregion 16) and the urea plants in Sattahip, Thailand (subregion 3), Singapore (subregion 10), and in Batangas in Middle Luzon, Philippines (subregion 23). Since the present solution is less costly than the one which included plant output constraints (see below), it would suggest that the economies resulting from the concentration of ammonia production in a few locations outweigh the additional transport costs. The low costs of transporting natural gas in LPG tankers within the ASEAN region certainly contributed to this result.

The Malaysian market, which in the former solution, was served by the Batangas plant in the Philippines, is, in the present solution, served by the plant in Singapore. With the plant at Ormoc on Leyte in the Philippines excluded from the present solution, the entire Philippine demand is met by the plant in Batangas. The other market shares remain relatively unchanged from the first solution.

The total annual cost to the ASEAN region of implementing the present solution works out to U.S.$21.86 million or U.S.$20.80 per ton of urea. This represents an annual gain of U.S.$4.5 million over the least-cost solution that included plant output constraints. It clearly demonstrates the potential advantage of pooling resources in order to implement the present solution. Specifically, some kind of capital sharing scheme to supplement this resource in Indonesia and the Philippines would be required. Compared with the average F.O.B. import price of urea in the ASEAN region the present solution produces an annual savings of U.S.$93.76 million or U.S.$89.2 per ton of urea.

C. *With Distributional Weights*

The distributional weights were applied to the solutions which do not contain skilled labor and capital constraints as these are considered more indicative of what is achievable for the ASEAN region. When applied to the solution for the aluminum industry, we find that of the four best solutions, the third best becomes first best followed by what was originally first best, fourth best, and second best. The third best solution, which, with the application of the distributional weights becomes first best, differs from what was originally first best by excluding the aluminum plant in Iligan (subregion 26) which leaves only two aluminum plants in subregions 3 and 11 in the final stage of production. The other locations include two bauxite mine sites (subregions 7 and 12) and one alumina plant in subregion 11.

Applying the distributional weights to the four best solutions to the regionally integrated urea fertilizer industry (without plant output constraints) we find that the least-cost solution moves to the fourth position and the other three solutions move up one position while retaining the same order. This is not surprising in view of the fact that the least-cost solution includes an urea fertilizer plant in Singapore (subregion 10) and excludes the one in Ormoc on Leyte, Philippines (subregion 25). Singapore has the lowest distributional weight in the region due to its negligible market for urea and its relatively higher level of income. The Philippines occupies a somewhat middle position on the distributional scale. The second best solution which becomes first best contains two natural gas feedstock production points in subregions 13 and 16, two ammonia plants including the existing one in subregion 13 and a new plant in subregion 16 and six urea plants including two existing ones, in subregions 13 and 14 and four new plants in subregions 3, 16, 23, and 25.

VII. CONCLUSIONS

The results show that there are substantial gains to be realized by the countries in the ASEAN region from establishing the aluminum and urea fertilizer industries on a regional basis. In terms of constant mid-1973 prices, the savings for the regionally integrated aluminum and urea fertilizer industries work out to U.S.$374 and U.S.$84.9 per ton of aluminum metal and urea fertilizer, respectively, when compared with the most likely alternative of imports from outside the region. This, of course, only refers to static allocative efficiency gains, not to mention the benefits that are likely to accrue through the transmission of industrial linkage and employment effects.

Furthermore, the removal of plant output constraints, other than that imposed by the state of technology, namely, skilled labor and capital, results in considerable additional gains for the participating countries through the greater realization of economies of scale. For the aluminum industry, the additional gain amounts to U.S.$17 per ton of aluminum metal whereas for the urea fertilizer industry, it is U.S.$4.28 per ton of urea.

Distributional weights have been derived based on the goal of preserving the stability of the integration scheme itself through the minimization of possible conflicts of interest between the participating countries. The solutions which are adjusted for distributional considerations are likely to be the most practicable in the sense that they contribute more to the stability of the integration scheme than would the solutions based solely on efficiency. Furthermore, the efficiency loss, for the cases considered, resulting from their adoption is fairly small.

The findings for both the aluminum and urea fertilizer industries suggest that the ASEAN countries may find it useful to employ a model such as the one used in this study, before selecting the sites for new plants in industries to be established on a regional basis. The findings show that the indiscriminate selection of plant sites within the ASEAN region, with its diverse industrial location characteristics, could easily lead to a solution which would render a particular integration scheme, at least from a static allocative efficiency point of view, uneconomical, not to mention the unnecessary incurrence of extra cost. Furthermore, a fairly rigorous demonstration of the advantages as well as the objective procedures and methods that were used to arrive at a particular solution, which the model affords, may be expected to complement diplomatic efforts to convince prospective participating countries. Hopefully by identifying and attempting to deal with the economic problems associated with the development of industries on a regional basis in the ASEAN region, this analysis has made the political choices that will have to be made both clearer and more likely to be rationally based.

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