OPTIMUM ALLOCATION OF OUTPUT FROM SAUDI ARABIAN PETROCHEMICAL COMPLEXES

Leslie A. Carmichael and Jaffer Syed*

Chemical Technology Center
SRI International
Menlo Park, California, 94025 U.S.A.

الخلاصة :

إن هذه المقالة تشرح نموذجاً لتطور الإتساع العالمي للصناعات البتروكيماوية والتي طورها مركز العمليات الكيميائية الإقتصادية في الـ إس آر آي العالمي (SRI international) وهذا النموذج يجمع جميع المصانع المقامة حالياً والمخطط لها مستقبلياً لإنتاج الإيثيلين ومشتقاته .

ولقد أُستمدت المعلومات الجانبية والسمتخدمة في هذا النموذج لكل من الإنتاج الإقتصادي لكل مصنع وتكلفة الشحن والتعرفة من عديدٍ من الأسواق . أما عمليات الطلب لـلأسواق فقد حُددت خارج هذا النموذج . ولقد أوجدت صيغ لإعطاء الحل الأمثل لهذه المشاكل لتحديد أسعار السوق والحصة الإنتاجية لكل مصنع في السوق . وقد أتضح أنه بإستخدام هذا النموذج يمكن الحصول على إنتاج الحصة المثلى من مصانع البولي إيثلين . ونتيجة لهذا هو أخذ وحدات سابك المنتجة للبولي إيثلين كمثال لذلك .

ووجد أيضاً أن دول حوض الباسفك والدول الأوروبية والواقعة على حوض البحر الأبيض المتوسط ودول أمريكا الجنوبية هي السوق المربح لهذه المنتجات وذلك بأخذ ٩٠٪ من الإنتاج مشكلاً بالبولي إيثلين العالي الكثافة .

*Mailing address for correspondence:
Chemical Process Economics Center SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025 U.S.A.

0377–9211/85/040339–11$01.10

ABSTRACT

The paper describes a model of the worldwide petrochemical industry developed by the Chemical Technology Center of SRI International. The model incorporates all existing and planned plants for ethylene and its derivatives. The production economics of each plant, and the transportation costs and tariff into various markets are used to model the supply side. Demand functions for markets are specified exogenously. An optimization problem is formulated to determine market prices and the output allocation of each plant to the markets. The use of the model for the optimum allocation of output from polyethylene plants is shown and the results of the optimum allocation are illustrated with the example of SABIC's polyethylene units. The profitable markets for the output of these units are found to be Pacific Basin, Mediterranean Europe and South America, with 90% of production consisting of high density polyethylene.

OPTIMUM ALLOCATION OF OUTPUT FROM SAUDI ARABIAN PETROCHEMICAL COMPLEXES

INTRODUCTION

Saudi Basic Industries (SABIC) and its joint venture partners will complete the start-up of their petrochemical facilities in 1986, ahead of schedule. The SABIC facilities will add approximately 1.6 million tonnes per year of ethylene capacity to the existing world capacity of 45 million tonnes per year, an increase of about 3.5%. A change of 3.5% would not seem sufficiently large to upset the competitive equilibrium of the worldwide ethylene derivative industry. However, when world export markets for derivatives are examined, Saudi production amounts to approximately 35% of the total export movements. Thus, SABIC and its joint venture partners may effect a significant rearrangement in the export movements of ethylene derivatives [1].

The approaching start-up of the Saudi Arabian petrochemical facilities has thus resulted in widespread speculation in the petrochemical community about the likely destination of Saudi exports, as well as the pricing policy of SABIC and its joint venture partners. In response, the Chemical Process Economics Center of SRI International has developed a model of the worldwide ethylene derivative industry that contains the operating economics of nearly 1000 individual operating units. This cost (supply curve) model has been used for a competitive analysis of plant outputs. To arrive at competitive trade flows, an optimization problem has been posed and solved. The trade flows thus obtained for the Saudi Arabian plants represent the optimum allocation of output from the petrochemical complexes operated by SABIC and its joint venture partners.

SUPPLY CURVES

The rank ordering of the supply of a product according to the unit production cost of individual plants yields the local or free-on-board (FOB) supply curve for that product. Landed supply curves can be derived from local supply curves by adding transportation, duties, and distribution costs to the FOB production costs.

Our supply curves are based on cash production costs, which are defined as the sum of the raw materials, utilities, labor, maintenance, general and administrative expenses, and depreciation. (Although the 5% per year depreciation charge is not a strictly cash expenditure, we have included it in our production costs to provide a measure of the effect of plant age on production economics.)

Transfer prices, the prices at which captively produced products are transferred to downstream operations, are the subject of endless negotiations within individual companies. Instead of attempting to establish transfer prices, we have transferred upstream products to downstream units at the cost to the upstream unit in the case of full or joint venture ownership of both units.

To date, we have developed supply curves for the following ethylene derivatives:

- Ethylene oxide/ethylene glycol
- Ethyl benzene/styrene
- Ethylene dichloride/vinyl chloride/polyvinyl chloride
- Low-density polyethylene (LDPE)
- High-density polyethylene (HDPE)
- Linear low-density poly-ethylene (LLDPE)

SRI has divided the market for each polyethylene resin into two segments: commodity and high specification resins. Commodity resin markets are characterized by relatively large volumes served by a limited number of resin grades. High specification markets, on the other hand, are characterized by a large number of small volume markets served by a large number of resin grades, each of which is tailored to suit specific end uses. The commodity resin markets are highly competitive; price and production costs are thus of controlling importance. The high specification resin markets show some monopolistic characteristics because the number of plants technically capable of making resins to the desired specifications is limited. Therefore, the prices of high specification resins are more stable, and the profit margins are generally higher than those for commodity grades.

The geographic coverage of our supply curve model includes the major industrialized areas (Japan, the United States, Western Europe), Latin America, the Middle East, the ASEAN countries, Oceania, and the Far East (Taiwan and South Korea).

The nature of supply surves is illustrated in Figure 1, which shows the FOB supply curve of U.S. commodity grade HDPE producers projected to 1987.

COMPETITIVE ALLOCATION OF OUTPUT

In the competitive analysis, each plant is free to distribute its output to any market, subject to the constraint that the total supply for the product in that market be less than or equal to demand. The quantity produced and the associated costs of production are determined exogenously. The demand for all products is assumed to have constant elasticity with respect to price. The demand curve is represented by:

$$Q = AP^{-e} \qquad (1)$$

where:

Q is the quantity
P is the price
e is the price elasticity of demand
A is a constant.

Because the demand for olefin derivatives is highly inelastic, we have chosen a value of $e = 0.2$. The value of A is determined by specifying a price-quantity pair and solving for A in Equation (1).

The competitive allocation of output is based on the purely economic criterion of return per unit of product sold in any market during the period considered. Strategic marketing considerations and existing company prices are outside the scope of our competitive analysis with one exception: the cost of exiting from the chemical business is generally high; there is no market for used (shut-down) plants, and in some countries government regulations have substantially increased the social costs of exiting.

THE MODEL

Our model solves for (1) market prices of the various products for a given period and (2) the competitive allocation of each plant's production of these products among the markets on the basis of those prices. The world is divided into a number of market regions, and each plant is assigned a region for its local market. Market demand is represented by the demand function for the relevant period. Each plant can distribute its output to its local market, as well as to any other market.

In setting up the problem of competitively allocating each plant's output among different markets, our analysis has been based on the purely economic criterion of returns per unit of product sold in any market during the period being considered.

Using the assumptions stated above, and a set of market prices, we can obtain the allocation which gives a joint maximum of returns to all plants, by solving the following problem.

Minimize

$$\sum_{i=1}^{n_p} \sum_{j=1}^{n_m} \sum_{k=1}^{n_r} (c_{ijk} - p_{jk}) C_{ik} x_{ijk};$$

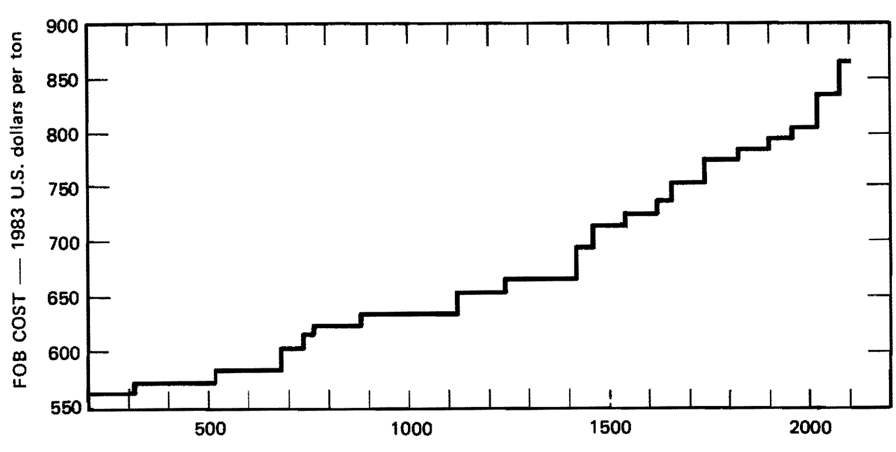

Figure 1. HDPE-Commodity Grade Supply Curve for U.S.A. in 1987

Subject to

$$\sum C_{ik} x_{ijk} \leqslant D_{jk}(p_{jk}) \qquad j=1,\ldots,n_m \quad k=1,\ldots,n_r$$

$$\sum_{j=1}^{n_m} \sum_{k=1}^{n_r} x_{ijk} \leqslant \text{maxcu}_i \qquad i=1,\ldots,n_p \tag{2}$$

$$\sum_{j=1}^{n_m} \sum_{k=1}^{n_r} -x_{ijk} \leqslant -\text{mincu}_i \qquad i=1,\ldots,n_p$$

$$x_{ijk} \geqslant 0 \qquad i=1,\ldots,n_m \quad j=1,\ldots,n_p \quad k=1,\ldots,n_r$$

where:

n_p = number of plants;
n_m = number of markets;
n_r = number of products;
c_{ijk} = delivered cost per unit of product k to market j, from plant i;
p_{jk} = market price of product k in market j;
C_{ik} = productive capacity per year of plant i when producing product k;
x_{ijk} = fraction of the productive capacity of plant i, when producing product k, allocated to market j;
$D_{jk}(p_{jk})$ = demand for product k in market j, at price p_{jk};
maxcu_i = maximum capacity utilization rate of plant i;
mincu_i = minimum capacity utilization rate of plant i.

For an arbitrary set of market prices $\{p_{jk}: j=1,\ldots,n_m; k=1,\ldots,n_r\}$, the joint optimum of Problem (2) is such that individual plants may generally improve their returns by reallocating their output. In our method, we solve Problem (2) interatively with a new set of prices and corresponding demands until we obtain a set of prices and output allocation that is individually optimal for every plant.

Problem (2) can be rewritten in a block diagonal structure as follows:

Minimize

$$\mathbf{z}_1\mathbf{u}_1 + \mathbf{z}_2\mathbf{u}_2 + \ldots + \mathbf{z}_{n_p}\mathbf{u}_{n_p}$$

Subject to

$$\begin{aligned} \mathbf{A}_1\mathbf{u}_1 + \mathbf{A}_2\mathbf{u}_2 + \ldots + \mathbf{A}_{n_p}\mathbf{u}_{n_p} &\leqq \mathbf{d} \\ \mathbf{B}_1\mathbf{u}_1 \qquad\qquad &\leqq \mathbf{b}_1 \\ \mathbf{B}_2\mathbf{u}_2 \qquad &\leqq \mathbf{b}_2 \\ \mathbf{B}_{n_p}\mathbf{u}_{n_p} &\leqq \mathbf{b}_{n_p} \\ \mathbf{u}_1, \mathbf{u}_2, \ldots, \mathbf{u}_{n_p} &\geqslant 0. \end{aligned} \tag{3}$$

where variables in bold type represent vectors with the following definitions:

For $i=1,\ldots,n_p$ and $N=n_m \times n_r$

$u_i = (x_{i11}, x_{i21}, \ldots, x_{i,n_m,1}, x_{i,1,2}, \ldots, x_{i,n_m,2}, \ldots, x_{i,n_m,n_r})$ — an N vector

$z_i = [(c_{i11} - p_{11})C_{i1}, (c_{i21} - p_{21})C_{i1}, \ldots, (c_{i,n_m,1} - p_{n_m,1})C_{i1}, (c_{i12} - p_{12})C_{i2}, \ldots, (c_{i,n_m,2} - p_{n_m,2})C_{i2}, + \ldots (c_{i,n_m,n_r} - p_{n_m,n_r})C_{i,n_r}]$ — an N vector

$$A_i = \begin{bmatrix} C_{i1} & & & & & \\ & \ddots & & & & \\ & & C_{n_m,1} & & & \\ & & & C_{i2} & & \\ & & & & \ddots & \\ & & & & & C_{n_m,2} \\ & & & & & & \ddots \\ & & & & & & & C_{n_m,n_r} \end{bmatrix}$$

— an $N \times N$ matrix

$$\mathbf{B}_i = \begin{bmatrix} 1 & 1\ldots & 1 \\ -1 & -1\ldots & -1 \end{bmatrix} \quad \text{— a } 2 \times N \text{ matrix}$$

$$\mathbf{b}_i = \begin{bmatrix} \text{maxcu}_i \\ -\text{mincu}_i \end{bmatrix}$$

$\mathbf{d} = (D_{11}, D_{21}, \ldots, D_{n_m,1}, D_{12}, \ldots, D_{n_m,2}, \ldots, D_{n_m,n_r})$ — an N demand vector

With the block diagonal structure of Problem (3), the problem can be solved using the decomposition algorithm for linear programs [2].

Let

$$U_i = \{\mathbf{u}_i: \mathbf{B}_i\mathbf{u}_i \leqslant \mathbf{b}_i, \mathbf{u}_i \geqslant 0\} \qquad \text{for } i=1,\ldots,n_p$$

Since U_i is a bounded polyhedral set, any point $\mathbf{u}_i \in U_i$ can be represented as a convex combination of a finite number of extreme points of U_i. Thus

$$\mathbf{u}_i = \sum_{l=1}^{t_i} \lambda_{il} \mathbf{u}_i^l$$

$$\sum_{l=1}^{t_i} \lambda_{il} = 1 \tag{4}$$

$$\lambda_{il} \geqslant 0 \qquad l=1,\ldots,t_i$$

where $\mathbf{u}_i^l$ are the extreme points of set U_i and t_i is the dimension of subspace U_i. Using the above relation for u_i, problem (3) can be rewritten as

$$\text{Minimize} \quad \sum_{i=1}^{n_p} \sum_{l=1}^{t_i} (\mathbf{z}_i \mathbf{u}_i^l)\lambda_{il}$$

$$\text{Subject to} \quad \sum_{i=1}^{n_p} \sum_{l=1}^{t_i} (\mathbf{A}_i \mathbf{u}_i^l)\lambda_{il} \leqslant \mathbf{d} \tag{5}$$

$$\sum_{l=1}^{t_i} \lambda_{il} = 1 \qquad i=1,\ldots,n_p$$

$$\lambda_{il} \geqslant 0 \qquad j=1,2,\ldots,t_i$$

This is the master problem with $N+np$ constraints, that is to be solved for λ_{il}.

To solve problem (4) we set up the initial tableau as follows:

	Basis	Inverse	RHS
1 ↑ N	w	0	$\mathbf{w}^T\mathbf{d}$
↓ ↑	I	0	d
np ↓	0	I	1

where the identity matrix at the top left represents slack variables, all of which are basic, and **w** represents the cost of not supplying one unit of product to the market. The objective function is $\mathbf{w}^T\mathbf{d}$ because all slack variables are initially set equal to the market demands. The identity matrix on lower right represent exactly one variable (e.g., λ_{i,l_i}) from each block i. Each λ_{i,l_i} is set equal to 1, and the corresponding extreme point $\mathbf{u}_i^{l_i}=0$. Clearly, the solution given by initial tableau is infeasible unless all mincu_i are 0. Before describing how we obtain a starting feasible solution, we set forth the solution using the decomposition algorithm to introduce the needed notations.

DECOMPOSITION ALGORITHM

Suppose that we have a basic feasible solution of (4) with an $(N+n_p)\times(N+n_p)$ basis B. Denoting the dual variables corresponding to the first two sets of constraints in (4) by $(\mathbf{w},\alpha)=\hat{\mathbf{Z}}_B\mathbf{B}^{-1}$, where $\hat{\mathbf{Z}}_B$ is the cost of the basic variables with elements $\hat{z}_{il}=\mathbf{z}_i^T\mathbf{u}_i^l$ for λ_{il} in the basis, the tableau corresponding to a feasible solution is shown below,

$(\mathbf{w},\alpha)$	$\hat{\mathbf{Z}}_B\mathbf{d}'$
$\mathbf{B}^{-1}$	$\mathbf{d}'$

where $$\mathbf{d}'=\begin{bmatrix}\mathbf{d}\\ \mathbf{1}\end{bmatrix}$$

is an $N+n_p$ vector. The solution to this problem can be improved as long as there is a solution for a plant allocation $\mathbf{u}_i^l$ such that

$$(\mathbf{w},\alpha)\begin{pmatrix}\mathbf{A}_i\mathbf{u}_i^l\\ \mathbf{e}_i\end{pmatrix}-\mathbf{z}_i\mathbf{u}_i^l>0 \tag{6}$$

where $\mathbf{e}_i$ is a unit vector with 1 as the ith element. That is, at optimality the following conditions must hold.

$$\lambda_{il} \text{ is nonbasic} \rightarrow \mathbf{w}\mathbf{A}_i\mathbf{u}_i^l+\alpha_i-\mathbf{z}_i\mathbf{u}_i^l\leqslant 0 \tag{7}$$

These conditions are verified by solving the following subproblems:

$$\text{Maximize} \quad (\mathbf{w}\mathbf{A}_i-\mathbf{z}_i)\mathbf{u}_i+\alpha_i \tag{8}$$

$$\text{Subject to} \quad \mathbf{u}_i\in U_i$$

If the objective function of any of these problems is >0, the corresponding solution $\mathbf{u}_i^l$ is saved and λ_{il} is introduced in the basis.

FINDING A STARTING FEASIBLE SOLUTION

Starting with the initial tableau, we obtain a basis corresponding to a feasible solution by repeating the following steps for each of the n_p plants:

1. Construct relative cost vector $\mathbf{w}\mathbf{A}_i-\mathbf{z}_i$ in descending order.
2. Allocate the output at the minimum capacity utilization rate, mincu_i of plant i to markets in the descending order of the cost vector as long as the slack variables are greater than a small positive number. This is done to prevent degeneracy caused by having a slack variable with a value of zero in the basis.
3. Adjust the values of the slack variables by subtracting the quantity supplied to a market.
4. Introduce the solution $\mathbf{u}_i^l$ in the basis while making nonbasic the previous λ_{i,l_i} corresponding to solution $\mathbf{u}_i^{l_i}=0$.

SOLUTION OF THE OVERALL PROBLEM

The overall problem of determining price and quantity allocations is solved as described below.

1. Set $k=1$, the iteration counter.
   Set $\mathbf{p}(1)=\mathbf{p}_0$, an estimate of market prices
   $$\mathbf{p}(\cdot)=(p_{11}, p_{21}, \ldots, p_{n_m,1}, p_{12}, \ldots, p_{n_m,2}, \ldots, p_{n_m,n_r})$$
   $\mathbf{w}(0)=\mathbf{0}$.
2. Evaluate $\mathbf{d}(k)$, market demands using demand functions $\mathbf{D}(\cdot)$ for given $\mathbf{p}(k)$.
3. If $i=1$, set $\mathbf{p}(1)=P_{\max}$, where $P_{\max}$ is a number about twice the average of market prices.
4. Solve the LP with $\mathbf{p}(k)$ and $\mathbf{d}(k)$ and return the solution $\mathbf{u}_i(k)$, $i=1,\ldots,n_p$ and the dual vector $\mathbf{w}_i(k)$.
5. If each $|\mathbf{w}_i(k)| \leqslant E$ an arbitrarily small number, stop.
6. If $k=1$, $\mathbf{p}(k+1)=\mathbf{p}(k)+\mathbf{w}(k)$, otherwise
   $\mathbf{p}(k+1)=\mathbf{p}(k)+[\lambda \cdot \mathbf{w}(k-1)+\lambda \mathbf{w}(k)]$
   $0<\lambda<1$.
7. Set $k=k+1$ and go to 2.

Under the assumption that individual plants are price takers, the above solution gives us the set of market prices and allocation of plants' output. Another characteristic of the solution is that for a plant that can produce more than one product, the margin (the market price, minus the delivered cost) earned per kilogram of product, multiplied by the relevant productive capacity, must be the same for each product as well as for each market.

The result of the model is a set of 'supply curves,' based on the delivered costs of supplies to a market, the market prices and the corresponding demands in each market. Since we do not allow capacity additions or total plant shutdowns, the supply and demand do not equilibrate in all of the markets. Thus, our analysis is based on disequilibrium between supply and demand with quantity rationing through the use of mincu_i and maxcu_i. Figure 2 shows the supply/demand conditions when supply and demand equilibrate at p^* (Figure 2(*a*)) and when they do not (Figures 2(b) and 2(c)).

APPLICATION

The model was applied to the world polyethylene (PE) industry to analyze the effects of a significant increase of trade flows in PEs owing to the start-up of Saudi Arabian plants.

Polyethylenes are classified into three categories: high density (HDPE), low density (LDPE), and linear low density (LLDPE). On the basis of the production capabilities of different types of polyethylene, the PE plants can be classified into four categories: HDPE only, HDPE and LLDPE, LDPE and LLDPE, and LDPE only. With the introduction of two grades, commodity (C) and high specification (S) for each of the PEs, a plant can produce up to four differentiated products. We denote the six different PEs as HDPE-C, HDPE-S, and so on.

The period of analysis is the year 1986, when all Saudi PE plants are expected to operate at full capacity. SABIC's plants use Union Carbide's Unipol technology and thus are capable of producing LLDPE and HDPE in the same equipment. The production rates for HDPE commodity grades, and LLDPE commodity and speciality grades equal the nameplate capacity. The production rate for specialty grade HDPE is 90% of the nameplate capacity. The capacities of SABIC's PE plants for various PEs are summarized in Table 1.

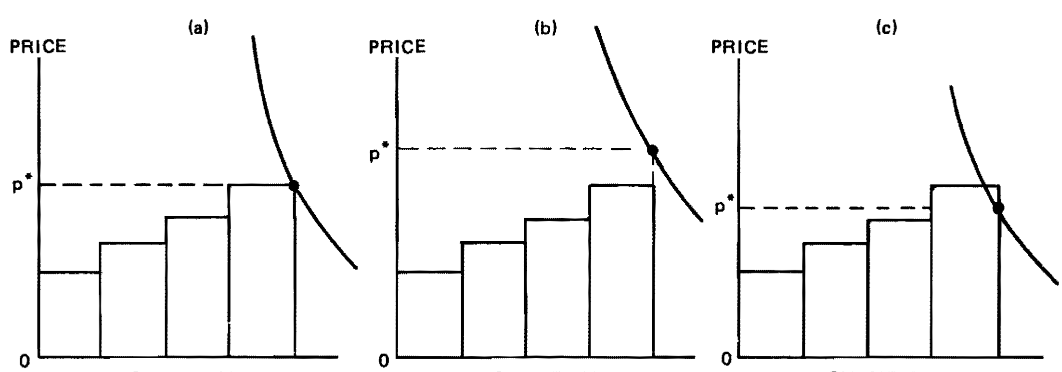

Figure 2. Possible Supply/Demand Conditions in Disequilibrium

Table 1

Company	City	Capacities in kilotons/year			
		LLDPE-C	LLDPE-S	HDPE-C	HDPE-S
SABIC/Exxon	Al Jubail	260	260	260	234
SABIC/Mitsubishi	Al Jubail	130	130	130	117
SABIC/Mobil	Yanbu	290	290	290	261

In 1986, there will be 210 PE plants in operation throughout the world. We have considered 22 market regions, each with six demand functions corresponding to each of the 6 PEs. Thus, the overall problem has 27 720($=210\times22\times6$) variables and ($132+210\times8$) constraints. The annual growth rates for PE demand is assumed to be 5.3% for the USA, 4% for Japan and 3% for Western Europe. For developing countries we have assumed higher growth rates, ranging between 8–12%. For determining production costs we have assumed the crude oil (Saudi Arabian Light) price of$29/barrel. The inflation rate is assumed to be 5%/yr for the period 1983–1986.

Since the plants represent large investments, and have an economic life of about 20 years, an exit from the market involves high costs. Typically, owners operate plants for some time even at a loss in order to maintain market share and existing customer base. On the other hand, some plants are owned by the respective governments and are not operated strictly according to the financial returns they produce. To account for these realities, we provide a minimum capacity utilization factor for each plant. The net effect is a reduction in demand for the output of more efficient plants.

Table 2. Competitive Allocation of Qutput from SABIC'S Polyethylene Plants in 1986

Venture	Product	Market	Supply, Kton	1983$/Ton		
				Landed cost	Price	Margin
SABIC/Exxon	HDPE-C	South America–Pacific	24	1118	1231	113
SABIC/Exxon	HDPE-C	Indonesia	30	707	820	113
SABIC/Exxon	HDPE-C	South Korea	6	783	896	113
SABIC/Exxon	HDPE-C	Thailand	28	1024	1138	113
SABIC/Exxon	HDPE-S	South America–Atlantic	79	1160	1286	126
SABIC/Exxon	HDPE-S	South America–Pacific	9	1197	1323	126
SABIC/Exxon	HDPE-S	Thailand	20	1092	1218	126
SABIC/Exxon	LLDPE-C	ASEAN–South	13	933	1046	113
SABIC/Exxon	LLDPE-C	Taiwan	12	855	968	113
SABIC/Exxon	LLDPE-S	ASEAN–South	3	968	1081	113
SABIC/Mitsubishi	HDPE-C	W. Europe–Mediterranean	117	705	774	69
SABIC/Mobil	HDPE-C	W. Europe–Mediterranean	90	678	774	97
SABIC/Mobil	HDPE-C	W. Europe–North Sea	11	693	790	97
SABIC/Mobil	HDPE-C	Middle East	21	606	702	97
SABIC/Mobil	HDPE-C	Indonesia	25	724	820	97
SABIC/Mobil	HDPE-C	New Zealand	8	699	796	97
SABIC/Mobil	HDPE-S	Indonesia	17	774	882	108
SABIC/Mobil	HDPE-S	ASEAN–South	52	960	1067	108
SABIC/Mobil	LLDPE-C	Middle East	16	646	743	97
SABIC/Mobil	LLDPE-C	Indonesia	4	768	865	97
SABIC/Mobil	LLDPE-S	W. Europe–North Sea	1	758	855	97
SABIC/Mobil	LLDPE-S	South Korea	5	879	976	97
SABIC/Mobil	LLDPE-S	Taiwan	4	902	998	97
Exxon-USA	HDPE-S	U.S. Gulf Coast	97	740	806	66
Exxon-USA	HDPE-S	U.S. East Coast	46	777	843	66
Exxon-USA	HDPE-S	U.S. West Coast	27	806	872	66
Exxon-USA	LLDPE-S	U.S. Mid West	54	825	884	59
BPCHEM-UK	HDPE-C	W. Europe–North Sea	114	790	790	0

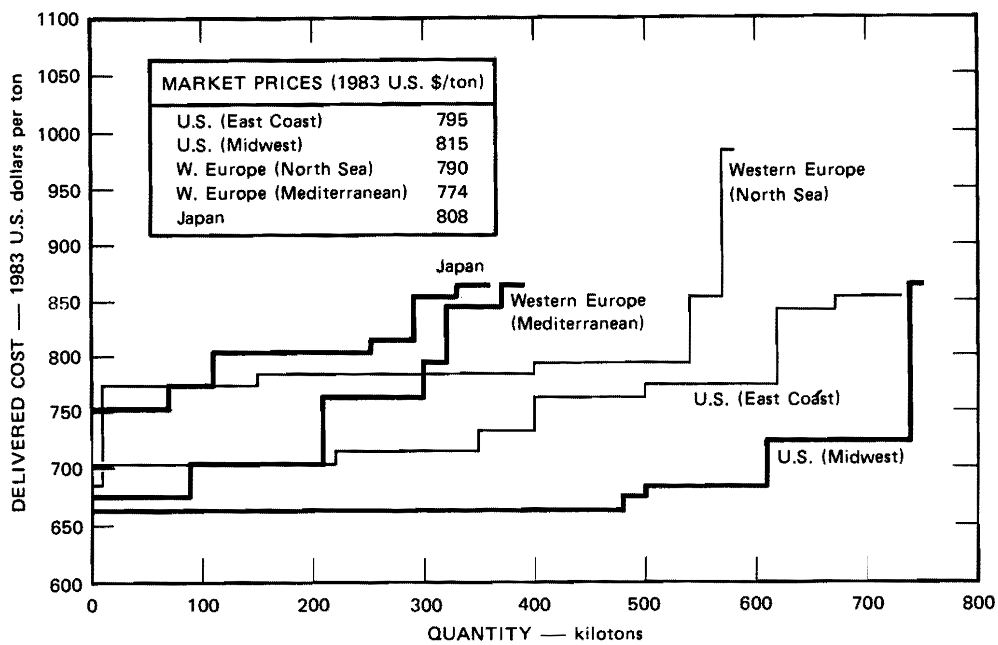

Figure 3. HDPE-Commodity Grade Supply Curves for Major Markets in 1986

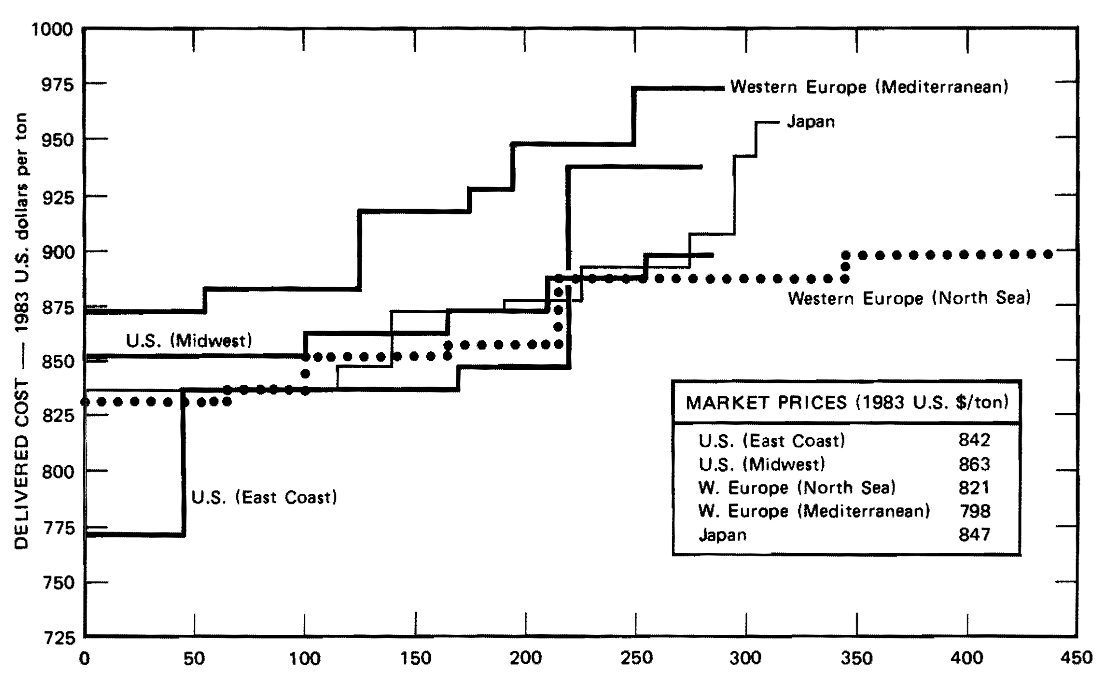

Figure 4. HDPE-Speciality Grade Supply Curves for Major Markets in 1986

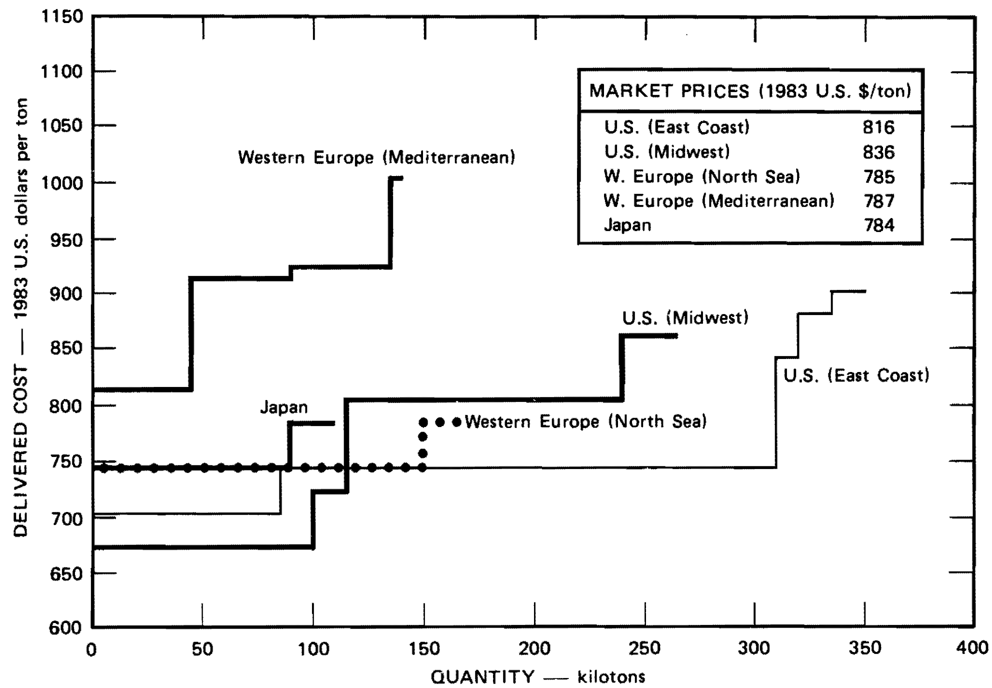

Figure 5. LLDPE-Commodity Grade Supply Curves for Major Markets in 1986

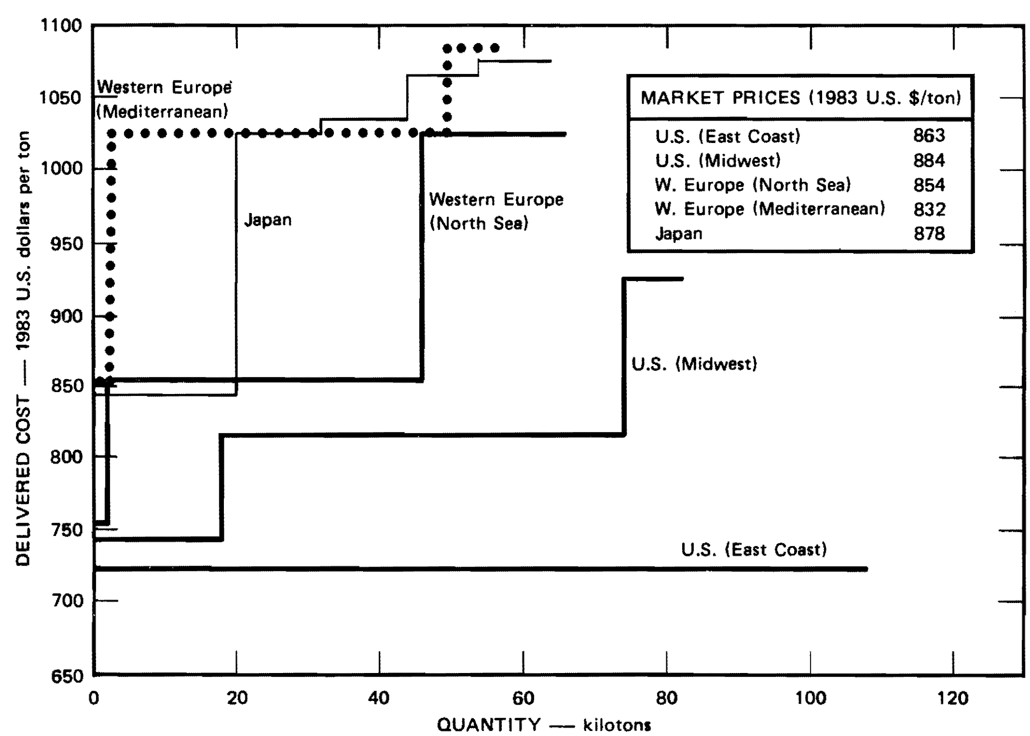

Figure 6. LLDPE-Speciality Grade Supply Curves for Major Markets in 1986

RESULTS

The competitive allocation of output from SABIC's polyethylene plants is given in Table 2.

As discussed earlier, the competitive allocation procedure not only allocates markets to individual producers, but, in the case of polyethylenes, it also splits production between the four PE grades. When the allocation is optimum, the margins earned by any given plant are such that they provide equal annualized earnings regardless of market and product grade. Thus, the margins for commodity grade HDPE and both grades of LLDPE, will be the same for a given plant regardless of markets. Because of the 10% lower production capacity with speciality grade HDPE, the margin will be 10% higher for this grade than that for the other three grades. The margin figures shown in Table 2 confirm the above thesis.

Table 2 also lists the landed costs of product from the SABIC facilities as well as the projected price for the product in the relevant market. Prices in excess of $1000/ton are the result of high import duties in the South American markets, in Thailand and in the ASEAN markets. For the sake of comparison, examples of efficient plants in USA and Europe are also given.

Examining the split between HDPE and LLDPE production, we note that over 90% of the output from the SABIC plants are allocated to HDPE. This favoring of HDPE over LLDPE should not be surprising since LLDPE is a relatively new product and demand for LLDPE is relatively low in the natural markets for SABIC's plants: the Pacific Basin and South America.

Finally, the supply curves for five major markets, East Coast and Mid West of the USA, North Sea and Mediterranean in Western Europe, and Japan are shown in Figures 3 through 6 for commodity and specialty grades of HDPE and LLDPE.

CONCLUSIONS

The optimum allocation of output from SABIC's polyethylene plants presented in this paper is based on purely economic considerations. There are of course a number of noneconomic objectives that a company such as SABIC may have. These considerations include but are not limited to the long term market prospects, company ties, and perceived long term profit potential. The reaction of existing producers to SABIC's entry may not be that response based on purely economic considerations. SRI is planning to integrate the model with an expert system to take into consideration likely behavior of the producers under various possible scenarios.

REFERENCES

[1] W. K. Johnson, 'World Wide Ethylene and Propylene Market'. *SRI Symposium*, Zürich, 1984.

[2] M. S. Bazaraa, and J. J. Jarvis, *Linear Programming and Network Flows*, New York: Wiley, 1977.

Paper received 13 February 1985; Revised 22 May 1985.