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ECONOMIC BACKGROUND OF CHEMICAL INTEGRATION – A CASE STUDY

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Abstract

In this second paper on chemical integration the author refines the usual relation of total costs equals fixed plus variable costs further by splitting the fixed costs into core, true fixed and capacity related fixed costs. A set of equations for a simplified definition of the returns on investment for an entire chemically integrated complex and individual production units in the manufacturing plant is given, from which the individual contributions of diversification and of chemical integration can be deduced. An example taken from practice is given.

INTRODUCTION

Chemical integration has been treated in a previous paper [1]. We call a production plant chemically integrated, if from one main raw material not only one single product and waste are made, but if the parallel, consecutive and waste products are separated to the highest possible extent and used to manufacture other useful chemicals, which fulfill a certain need and can be sold on the market. The advantages and risks are summarized in Table 1 [1].

TABLE 1

Aspects of chemical integration

Advantages of Integration
1. From one raw material more products, more markets served, more economic flexibility (products to most profitable markets and temporary withdrawal from depressed markets).
2. Better utilization of investments.
3. Lower storage requirements.
4. Lower investments in working capital.
5. No costs for intercompany transfer (sales, purchasing, packaging and border crossing).
6. Lower costs for intermediates (transport, analysis).
7. Higher yields for intermediates (quality requirements less sharp).
8. Scale increase.

Risks
1. Obsolescence of basic raw materials.
2. Non-scheduled long shut-downs of crucial up-stream units (?, because it can also happen to the supplier of raw materials!).

MANUFACTURING COSTS AND RETURNS ON INVESTMENT

In process economics handbooks generally the total production and selling costs C_i for manufacturing and marketing a product i in a production unit i are separated in the variable costs V_i and fixed costs F_i. The income from net sales S_i gives a gross return R_i of:

$$R_i = S_i - C_i = S_i - (V_i + F_i) \quad (1)$$

Per unit of product, if no stock changes take place, the gross margin is:

$$\dot{R}_i = \dot{S}_i - (\dot{V}_i + \dot{F}_i) \quad (2)$$

In this paper for demonstration purposes, the gross return on investment RoI_i is defined in a simplified form as:

$$\text{RoI}_i = R_i/\bar{I}_i = S_i - (V_i + F_i)/\bar{I}_i \quad (3)$$

We will abstain from considering the influence of taxes, interests, dividends, pay-outs to employees, the many differences in definitions of the average investments and DCF based RoI definitions, although in practice they should definitely be taken into account. For our purposes they would only obscure the facts we want to illustrate.

In order to understand the economic aspects of chemical integration, the application of eq. 1 is not sufficient and we have to split the fixed costs F_i into three different contributions to the fixed costs:

– N: the "core" costs [2], which relate to the fixed costs originated by the nucleus of every plant or company and its organisation. They relate to the staff personnel and I_N, the related investments for the staff accommodation and the "core" investment costs for utilities and auxiliaries.

– F_i: really fixed costs for the production plant i, mainly personnel in the plant itself and the additional personnel in the service and utility departments, originated by the addition of unit i to the manufacturing complex.

– $F_{\text{Cap}\,i}$: fixed costs, which are dependent on the capacity of production unit i and the additions required to the utilities and auxiliaries. They mainly include depreciation, maintenance, insurance and interest, and usually are expressed as a percentage or fraction of the investment in fixed assets I_i for the production unit i.

The variable costs V_i are linearly dependent on the production rate and mainly consist of raw materials, energy, packaging materials and interest on working capital. They equal $P_{Pi}\dot{V}_i$, if P_{Pi} is the production rate and $\dot{V}_i$ are the variable costs per unit of product.

With respect to the various cost items the following can be said:

The core costs. Every plant organisation in high technology process industries contains a nucleus of personnel, for example laboratory, engineering, maintenance, production, purchasing, shipping, marketing, accounting, personnel and safety managers, a managing director, controller, a medical attendant, market researcher, clerical staff, lawyer and their secretaries. This holds for organizations with at least 300–500 employees.

Of course a very small organization will not employ all the people mentioned and functions will be combined. Nevertheless core costs will not be correspondingly lower, because additional expenditures will be made for hiring outside consultants or a service fee will be paid to a parent company which can provide the same services. Also a "core" investment for offsite facilities and site development has to be made beside the "core" investment in industrial buildings.

The real fixed costs do not contain only the operating personnel for the production unit i, but also the additional staff required for services to production unit i in the analytical laboratory, administration and marketing departments and the costs related to the corresponding additional investments in utilities and auxiliaries.

The variable costs are assumed to be proportional to the production rate. We should realize, however, that for example the energy demand will never really be linearly dependent on the production rate: for example, heat losses will be almost independent of the production rate and, for example, a minimum reflux flow in distillation towers is necessary for keeping the trays wet, how small the production rate may be.

In principle different philosophies can be followed in accounting for the working capital; we assume that the working capital can be completely disposed of and recovered at closing down the production unit i and does not belong to the risk capital, so the normal bank interest rate or any rate determined by company policy, has to be earned. Then the interest on the working capital can be considered as a variable cost.

The total manufacturing costs for a product i produced in a plant with one production unit i and the corresponding utilities, auxiliaries and buildings are:

$$C_i = N + F_i + F_{\text{Cap } i} + V_i \tag{4}$$

The gross sales income from product i becomes:

$$R_i = S_i - C_i = P_{Si}\dot{S}_i - P_{Pi}\dot{C}_i \tag{5}$$

If no stock changes take place, $P_{Si} = P_{Pi}$, then the gross margin per unit of product i sold is:

$$\dot{R}_i = \dot{S}_i - \dot{V}_i - \frac{1}{P_{Si}}(N + F_i + F_{\text{Cap } i}) \tag{6}$$

and the gross return on investment for product i is:

$$\text{RoI} = \frac{P_{Si}\dot{R}_i}{\bar{I}_N + \bar{I}_i} \tag{7}$$

We notice that in order to make our equations not too complicated, we have introduced some simplifications and have left out terms to correct, for example, for stock changes and underload of the production unit.

SCALING-UP

In case we increase the capacity of the production unit i, investments in fixed assets I_i increase for the production unit and also for the corresponding utilities and auxiliaries. We normally use the so-called "six-tenth" rule:

$$I'_i = \left(\frac{\text{Cap}'\, i}{\text{Cap } i}\right)^n I_i, \text{ where } n = 0.6$$

In this case also $F_{\text{Cap } i}$ increases by $(\text{Cap}'\, i/\text{Cap } i)^n$ but, because n is smaller than 1, the gross margin increases. If for the smaller unit with sales and production volume of P eq. 6 is used, it can easily be calculated, that for the larger unit with a sales and production volume of P', holds:

$$\dot{R}'_i = \dot{S}_i - \dot{V}_i - \frac{1}{P'}\left\{N + F_i + \left(\frac{P'_i}{P_1}\right)^n F_{\text{Cap } i}\right\} \tag{8}$$

and it can easily be proven, that the gross margin improves with respect to the smaller unit:

$$\Delta\dot{R} = \left(1 - \frac{P}{P'}\right)\left(\dot{N} + \dot{F}_i\right) + \left\{1 - \left(\frac{P}{P'}\right)^{1-n}\right\}\dot{F}_{\text{Cap } i} \tag{9}$$

Mind, that $\Delta\dot{R}$ is always positive, because at scaling-up $P' > P$ and $n < 1$. We should be aware of the fact, that the so-called "six-tenth" rule is not exact [3] and in practice the situation is more complicated. If we have reached the technological maximum size of the unit (we are unable to make certain vital pieces of equipment larger), then $n = 1$. We have to build a second plant, so we duplicate instead of scaling-up.

There is also a technological minimum size of a plant – we put the smallest possible pieces of equipment in our mini-pilot plant – where $n = 0$. In the same mini-plant we can produce with the same investment 10 or 100 grams per day of a product. Between these extremes n will vary from zero to one. This is qualitatively

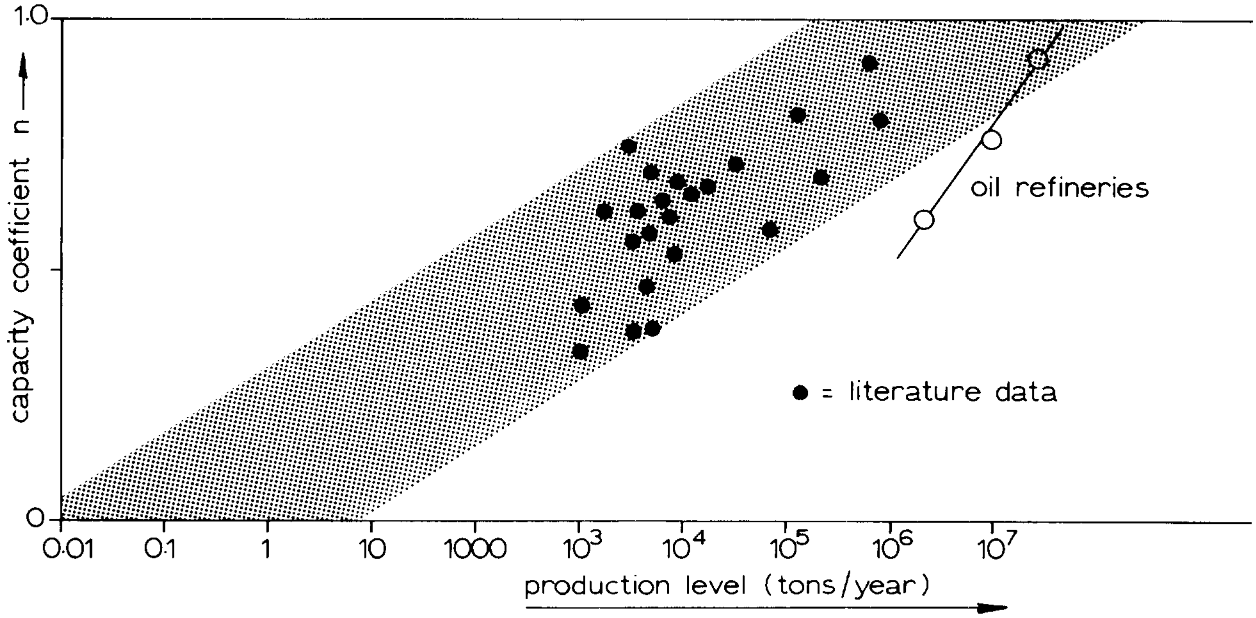

Fig. 1. Capacity coefficient versus production capacity for process plant (literature data from ref. 3).

illustrated in Fig. 1, where also the data of Timmerhaus and Reusch are given for hydro-skimming refineries [3].

Scaling-up of a single production unit, however, is often impossible, because there is no need in the market for more product (stagnant markets) or competition is so well established and has more than sufficient capacity available, that no addition of more capacity without serious margin deterioration is possible. In this case chemical integration could further reduce the cost prices and consequently improve the gross margin of the product *i*.

CHEMICAL INTEGRATION

We consider the same product *i*, of which the same amount P_{Si} can be sold in the market, see Fig. 2. Product *i* can be used as feedstock for subsequent production units 1, 2, . . . *x*. If P_{ji} is the production of *i* in the production unit *i* for subsequent consumption as raw material in unit *j*, the total production of unit *i* is:

$$P_{Si} + \sum_{1}^{x} jP_{ji} = \phi_i P_{Si}$$

Moreover, because more products are sold, the production unit *i* carries no longer all the core costs, but only a fraction ν_i of them. Of course:

$$\sum_{i}^{m} \nu_i = 1.00$$

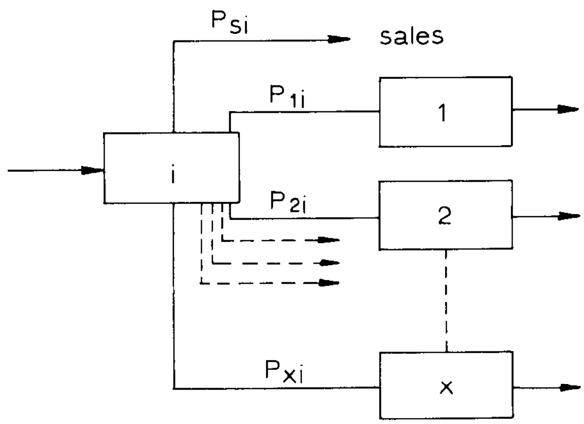

Fig. 2. Scheme for production unit *i* included in a chemically integrated complex.

where m is the number of products sold. The fraction ν_i is usually fixed rather arbitrarily by the accounting department; the matter of allocating costs is still vehemently discussed by accountants and many differing methods are in use.

In a chemically integrated complex the total costs for producing $\phi_i P_{Si}$ units of product i are:

$$C_{\text{int}\, i} = \nu_i N + F_i + \phi_i^n F_{\text{Cap}\, i} + \phi_i P_{Si} \dot{V}_i \tag{10}$$

The gross return per unit of product i sold becomes:

$$\dot{R}_{\text{int}\, i} = \dot{S}_i - \dot{V}_i - \frac{1}{\phi_i} (\nu_i \dot{N} + \dot{F}_i + \phi_i^n \dot{F}_{\text{Cap}\, i}) \tag{11}$$

In comparing eq. 11 with eq. 6 for one single product unit with the same sales output, we can see that the gross profit margine $\dot{R}_i$ has improved by:

$\Delta \dot{R}_i$ = equation 11 – equation 6 or

$$\Delta \dot{R}_i = \left(\frac{\phi_i - \nu_i}{\phi_i}\right) \dot{N}_i + \left(\frac{\phi_i - 1}{\phi_i}\right) \dot{F}_i + \left(\frac{\phi_i^{1-n} - 1}{\phi_i^{1-n}}\right) \dot{F}_{\text{Cap}\, i} \tag{12}$$

The improvement of the gross margin of product i is due to two effects:

Diversification effect. More products are made and more process units are included in the plant, so that not all core costs are carried by product i. This effect contributes $(1 - \nu_i)\dot{N}$ to the improvement of the gross margin.

Chemical integration effect. This effect consists of three contributions to the improvement of the gross margin:

- in the core costs $\left(\frac{\phi_i - 1}{\phi_i}\right) \nu_i \dot{N}$
- in the true fixed costs $\left(\frac{\phi_i - 1}{\phi_i}\right) \dot{F}_i$
- in the capacity related fixed costs $\left(\frac{\phi_i^{1-n} - 1}{\phi_i^{1-n}}\right) \dot{F}_{\text{Cap}\, i}$

The gross return on the whole chemically integrated complex has become:

$$\text{RoI}_{\text{tot}} = \frac{\sum_1^m i P_{Si} (\dot{S}_i - \dot{V}_i) - N - \sum_1^m i \frac{1}{\phi_i} (F_i + \phi_i^n F_{\text{Cap}\, i})}{\bar{I}_N + \sum_1^m i \phi_i^n \bar{I}_i} \tag{13}$$

Please bear in mind, that in this equation the working capital has implicitely been accounted for as an interest percentage in the production costs.

From eq. 13 we can conclude that the return on the investment in the entire chemical complex will become higher if:

- more (side) products are better utilized (ϕ_i larger);
- more diversification is applied and more production units are incorporated in the plant (ν_i smaller);
- the scale of the individual plants is smaller (n smaller).

For the individual product i RoI_i will depend on accounting policies of the company.

A CASE STUDY

The above equations will be elaborated with an example taken from practice, which has been studied extensively by company A. With a small single production unit i company A competed in the market with two other companies B and C. The capacity of company A's unit was 300 tons per year.

B had two production units of 1000 and 3000 tons per year capacity, respectively, the first fully loaded, the second operating at about 60% of the capacity.

Competitor C had one production unit of 1000 tons per year, working at 80% of its capacity.

Net sales price ex-plant after deduction of the variable sales expenses was 36.5 MU/kg of product *i*. (MU = monetary unit, approximately equal to one U.S. dollar.)

Company A lost money, but taking into account construction time for a larger plant, their marketing department felt they could sell in a few years up to 750 tons of *i* per year, without disturbing the market and depressing sales prices.

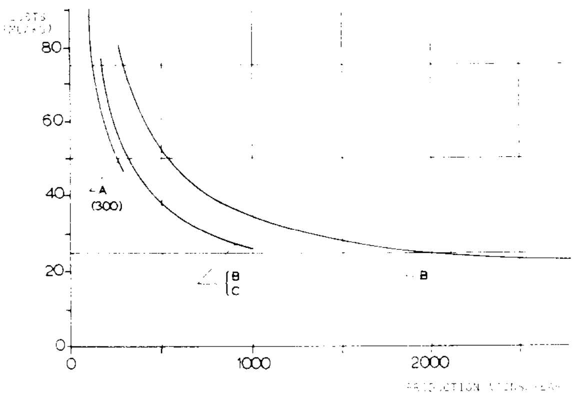

Fig. 3. Estimated price-volume relations for product *i* (relative position of competitors).

First a competition analysis, results are given in Fig. 3, where the well-known graph of price versus production volume is given for not fully loaded plants. After an extensive search of literature, patents and market information sufficient data could be obtained to calculate reliable cost prices for the plants of competitors B and C. We can see that the fully loaded small plant of company A can never compete even with the partly underloaded plants of competitors B and C. The projected plant of 750 tons annual capacity shows a small profit for company A. The relevant information is given in Table 2. If the average investments in fixed assets are equal to 60% of the original investments I_N and I_i, the gross RoI_i of 8.6% is

TABLE 2

Costs and RoI's in a single non-integrated unit for product *i* of company A

$\dot{S}_i$	=	36.5 MU/kg *i*	$\dot{V}_i$	=	17.5 MU/kg *i*
I_N	=	18,000,000 MU	$\dot{N}_i$	=	6.5 MU/kg *i*
I_i	=	20,000,000 MU	$\dot{F}_i$	=	4.4 MU/kg *i*
P_{Si}	=	750 tons *i*/year	$\dot{F}_{\text{Cap}\,i}$	=	5.5 MU/kg *i*

$I_i = I_{PU} + I_{AU} = (15 + 5) \times 1{,}000{,}000$ MU
Results for a fully loaded plant:
$\dot{C}_i = 33.9$ MU/kg *i* $R_i = 2.6$ MU/kg *i* RoI_i (eq. 7) = 8.6%

obtained. Whatever method of calculating RoI_i, results are far too low to justify investments in a larger production unit for *i*.

Company A, however, had built up chemical and technological knowhow around a pedigree of related chemicals, sufficient to integrate back and sidewards, according to the scheme in Fig. 4. With the related pedigree chemicals it

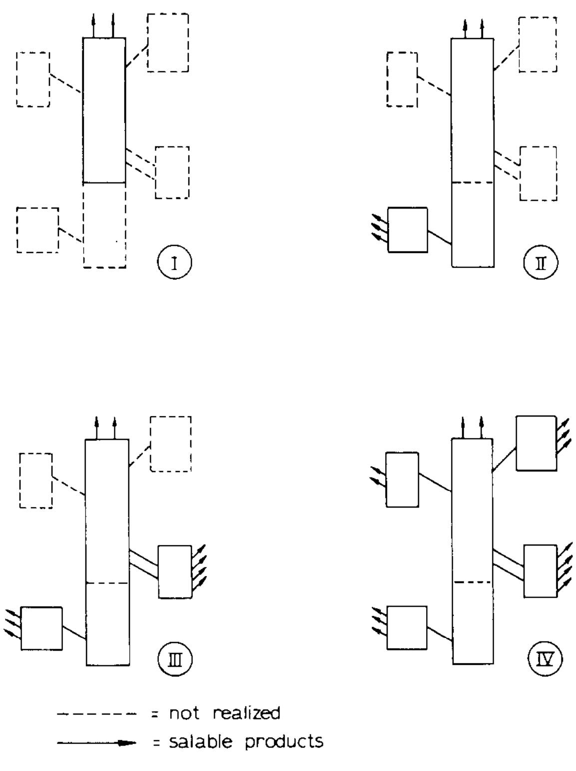

Fig. 4. An example of a chemical integration. Alternative projects I, II, III, IV with increasing integration.

would enter into three different markets, where the company already had a well established position, and into three other markets new to the company's marketing department. The way to full integration would successively lead to a gross RoI_i (eq. 13 for the whole complex as given in Fig. 5. The related information is given in the previous paper [1]. If we now consider $RoI_{int\,i}$ for the individual production unit for chemical i, we find the results as given in Table 3, using for the gross margin eq. 11 and for the $RoI_{int\,i}$ eq. 11 divided by the average total investment for product i.

A comparison of Tables 2 and 3 indicates a considerable improvement of the return on investment for product i, due to the chemical integration (for this particular accounting method of allocating costs). Under our assumptions the gross margin improvement of product i is for 54% due to the increase in the number of products produced and sold, and for 46% due to the chemical integration, despite the fact, that not one more ton of product i is sold.

The high contribution of 54% of the diversification effect is mainly caused by the fact, that company A had to compare a single non-integrated unit with an integrated complex. In case the integrated complex is added to an already highly diversified manufacturing plant – $\Delta\nu_i$ is small –, it can intuitively be felt that the contribution of the chemical integration effect to the gross margin improvement will be much higher (80 to 95%) than in this example, although the absolute value of the margin improvement will be smaller than in the example given. We should consider that $RoI_{int\,i}$ calculated will always be rather arbitrary, because of the transfer price setting for internal deliveries of subsequent plants. In determining the overall plant RoI_{tot} (eq. 13), however, they automatically fall away. Moreover, due to chemical integration $\dot{V}_i$, $\dot{F}_i$ and $\dot{F}_{Cap\,i}$ will be lower for integrated units than for single units, because of the advantages 5, 6 and 7, mentioned in Table 1.

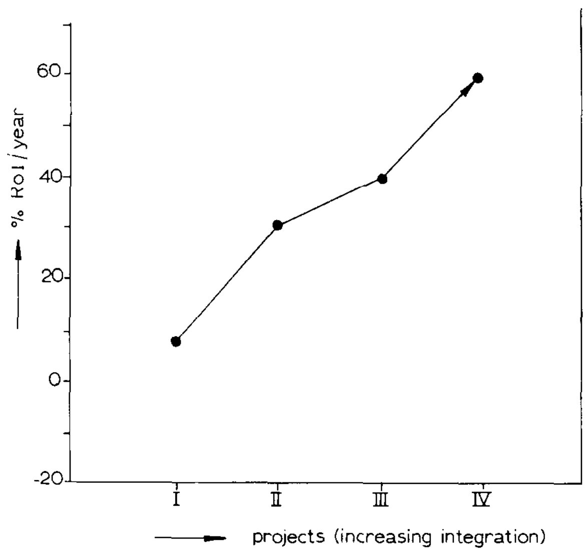

Fig. 5. RoI for alternative projects with increasing integration.

TABLE 3

Costs and RoI's in a chemically integrated production plant for product i of company A

Basic information:

S_i	=	36.5 MU/kg i	$\dot{V}_i$	=	17.5 MU/kg i [a]
I_N	=	18,000,000 MU	$\dot{N}_i$	=	6.5 MU/kg i
I_i	=	20,000,000 MU	$\dot{F}_i$	=	4.4 MU/kg i [a]
P_{Si}	=	750 tons i/year	$\dot{F}_{Cap\,i}$	=	5.5 MU/kg i [a]

Further information:

$\nu_i = 0.215$ $\quad \phi_i = 2.00$

$n = 0.55$ for the production unit + utilities and auxiliaries

$\phi_i^n I_i = 29{,}300{,}000$ MU and $\phi_i^n = 1.464$

Results: $\dot{C}_i$ = 24.4 MU/kg i

$R_{int\,i}$ = 12.1 MU/kg i

Margin improvement due to diversification: 5.1 MU/kg i (54%)
due to integration : 4.4 MU/kg i (46%)

$RoI_{int\,i}$ (eq. 15) = 45.6%

[a] Note: Mention that the variable and fixed costs for production unit i in Tables 2 and 3 are equal, so that the advantages mentioned in Table 1 under 5, 6 and 7 have not been accounted for.

CONCLUSIONS

We have shown that the more a chemical manufacturing complex becomes integrated, the higher the RoI is for the complex itself as well as for the individual products.

We have shown that this improvement is due to diversification (more products) and chemical integration.

In periods of stagnant or very slowly growing markets, where scaling-up of production units would only lead to more over-capacity, a higher degree of chemical integration is still a powerful tool for reducing costs. Far reaching specialisation in the way of chemical integration – provided the available technological know-how and the know-how of markets and needs are adequate and the competition cannot satisfy the needs better at lower costs – is then the only remaining method to spend the available investment money and know-how to the organization in a sensible way.

LIST OF SYMBOLS USED (MU = monetary unit)

Symbols

C	total production costs (MU/time)
Cap	production capacity of a plant (weight/time)
F	(really) fixed production costs (MU/time)
I	investment (MU)
N	core costs of a company or plant (MU/time)
P	(production or sales) volume (weight/time)
R	sales revenues (MU/time)
RoI	return on investment (–/time)
S	sales income (MU/time)
V	variable costs (MU/time)
m	total number of products sold from an integrated production complex (–)
x	total number of own production units, consuming product i as a raw material (–)
ϕ	production to sales volume ratio (–)
ν_i	fraction of core costs charged in product i (–)

Superscripts refer to

$\bar{}$	average
$'$	larger unit
n,n'	exponents in investment-capacity relation
$\cdot$	per unit of product sold

Subscripts refer to

AU	auxiliaries and utilities
Cap	capacity related
i	product i
int	in a chemically integrated complex
j	number of subsequent production unit, using i as a raw material
N	core costs
P	production
PU	process unit
S	sales

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