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BREAKING OF THE ENERGY COEFFICIENT:
CROSS-COUNTRY ANALYSIS FOR THE
CHEMICAL INDUSTRY

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WP-86-14

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FOREWORD

Many of today's most significant socioeconomic problems, such as slower economic growth, the decline of some established industries, and shifts in patterns of foreign trade, are inter- or transnational in nature. But these problems manifest themselves in a variety of ways; both the intensities and the perceptions of the problems differ from one country to another, so that intercountry comparative analyses of recent historical developments are necessary. Through these analyses we attempt to identify the underlying processes of economic structural change and formulate useful hypotheses concerning future developments. The understanding of these processes and future prospects provided the focus for IIASA's project on Comparative Analysis of Economic Structure and Growth.

Our research concentrates primarily on the empirical analysis of interregional and intertemporal economic structural change, on the sources of and constraints on economic growth, on problems of adaptation to sudden changes, and especially on problems arising from changing patterns of international trade, resource availability, and technology. In this paper one of the long-standing industries and the impact of its technological changes on energy consumption are considered. Econometric analysis of cross-country and time-series data helps to reveal the impact which is widely discussed in detailed engineering reports.

Anatoli Smyshlyaev

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INTRODUCTION AND GENERAL CHARACTERISTICS

The chemical sector is, on the basis of its structure and development, a particular case in the study of energy-intensive activities. This sector is far more complex than any other large energy consumer such as iron and steel, pulp and paper, or nonferrous metals; in these sectors there are a few products which can alternatively be produced through a limited number of processes; in the chemical sector out of a dozen raw materials up to 100.000 end products are produced, whose applications can be found practically in every activity. It is therefore impossible to undertake a kind of technical study of the energy consumption of the sector as a whole, especially as chemical products can not only be obtained by different processes, but, overall, through different 'routes', i.e. by using different raw materials and processes.

The role of energy products in the sector is not limited to fuel purposes: energy products (oil, gas, and coal) serve as feedstocks for the sector; oil and gas are particularly important and have nearly completely eliminated coal from feedstocks to form the basis of inorganic chemicals. For the sector as a whole, feedstocks represent 50% of the total energy consumed, and for petrochemicals the figure rises to two thirds*.

The main differences between the chemical industry and other energy-intensive sectors concern international trade, rates of growth, and the rationalization of the activity.

*Figures given in OECD [1].

Chemical products have an important place in world trade (12% in 1980*) unlike most of the energy-intensive products; only metallic products are comparable (8.9% of world trade), but generally exchanges of products such as cement, pulp or paper are limited. Likewise, chemical activities have always been fast growers as shown in Table 1 (adapted from CEPII [2]).

Table 1. Differences in annual growth rates from manufacturing average growth (market economies)

	1958-67	1967-71	1971-81
Chemicals	+2.4	+3.1	+1.1
Building materials	-1.3	+0.1	-0.3
Iron and steel	-0.5	-0.9	-1.3
Manufacturing (%)	6.6	5.2	2.5

The recession of the 1970s has hit the chemical sector, and in particular inorganic chemicals, which presented the fastest growing activity inside the branch during the 1960s, but the chemical sector remains among the leading activities.

Finally, the chemical sector is distinguished by the presence of activities with a high value-added content, which is in contrast to most of the energy-intensive sectors. Basic chemicals have mostly a low value-added content (the value-added/gross output ratio is about 29% to 37% for the seven countries studied*), but for the 'other chemical products' (ISIC 352) activities the value-added share is about 60%. This results from the heterogeneity of the sector which includes basic activities as well as very refined products. In comparison, the value-added/gross output ratio is about 30 to 40% for iron and steel, nonferrous metals, or pulp and paper.

The analysis of the sector's energy demand cannot be carried out in the same way as that of other sectors, such as iron and steel. There is no homogeneous representative product that could be the indicator of activity for the whole sector (like crude steel or paper or pulp) and that could be the denominator of the energy coefficient. The study of the industry from a commodity point of view can only be one step in the analysis; an energy-output study can only take place

*Figures in CEPII [2].

**France, FRG, Italy, Spain, Sweden, UK, and the USA.

with monetary output, which excludes simple 'technological progress' explanations of the decrease of the energy coefficient.

The scope of this paper is therefore limited. It would be out of question to try to sum up all the consequences of the crisis on such a heterogeneous sector without having a clear picture of the sector as a whole as well as of its links with the rest of the economy. Since the subject is centered on energy, the main problems related to it will be evoked. Because of its characteristics, petrochemicals is the sector which is most concerned with energy issues, depending heavily on energy products for its supplies and having very 'energy-intensive' products. The crisis is expected to encourage a shift in the world location of the petrochemical industry away from its traditional centers (Europe, Japan, USA) and therefore to decrease relatively the role of these centers in the world production of petrochemicals. On the other hand, the industrial crisis itself disturbs the structure of the industry and affects particularly the production of basic chemicals comparatively to other chemical products. These changes are likely to have consequences on the level of energy consumption of the chemical sector, and it has been attempted to link the level of energy consumption to the production of the most energy-intensive primary products.

This could clarify issues discussed in the UNIDO report "Analysis of the energy sector in relation to industrialized scenarios for the year 2000" [3], where the consumption of the sector was analyzed through a set of energy-intensive commodities, but where a decrease of the energy demand linked to a relative decrease of these commodities' production did not clearly appear.

STRUCTURAL CHANGE IN THE CHEMICAL SECTOR

This concerns primarily the petrochemical sector, which was the growth leader of the whole industry and was hard hit by the oil shocks. Inorganic chemicals have a smaller and declining share in the sector, and do not have the most energy-intensive products.

OECD made a specific study of the structural change in petrochemicals [1], which sums up the knowledge on the subject. As far as the structure of the petrochemical industry is concerned, it is interesting to note that the "backbone" of the sector is the ethylene chain; more generally, the study focuses on chains obtained from a set of a few important primary petrochemicals (propylene, butadiene, benzene, and ethylene, the four basic petrochemical products); the study of these basic products seems to catch most of the important features of the industry.

The feedstock structure is an important element which differentiates the USA from the two other traditional centers.

In the USA an important share of its feedstocks and fuel requirements is met by natural gas and its condensates; in contrast, Europe and Japan rely on petroleum products for more than 90% of their energy product needs. This is important since the shocks affected these regions differently: naphta prices in Europe multiplied by 14 between 1972 and 1981, whereas ethane prices multiplied by 8 in the USA. Such differences plead in favor of the inclusion of feedstocks in energy use. This may not be necessary for an analysis within one country, as M.J. Peck and J.J. Beggs state [4]: "Energy embodied in products has an entirely different set of substitution possibilities than energy used as fuel. (...) The traditional inclusion of petroleum feedstocks in industrial energy consumption is arbitrary. After all, the energy represented by lumber is never counted as industrial energy consumption." It is, however, necessary to consider feedstocks in the cross-country analysis in view of the important difference in feedstock structures, and the role feedstocks may play in the characterization of each country's industry. It is acknowledged that the trends in feedstock prices had given an advantage to the USA by the end of the 1970s, which was reflected in an increase of US exports. Several factors (deregulation of US gas prices, dollar exchange rate, etc.) have eventually attenuated this advantage.

In addition to the traditional centers (Europe, Japan, USA), the 'energy crisis' gave an opportunity to countries with a privileged access to energy products to have their own projects in petrochemicals. This applies mainly to two areas, the Persian Gulf and Canada (Alberta), and to the ethylene production through the ethane cracking route. The apparition of the new centers was made possible by many factors: oil prices raised petrochemical costs more than transport costs, variable costs are so important that the scale factor is not determinant enough to prevent geographical decentralization, etc. Ethane cracking is favored because it is the cheapest process in terms of capital costs and energy costs. The capacities are expected to be around 3 million tons in each of the regions (Persian Gulf and Alberta) by the end of the decade (between one fourth and one third of the current European and US production). Moreover, new plans are envisaged in other world regions, mainly to cover domestic demand. In any case, this reallocation is likely to cut down export possibilities for the traditional centers, the exact impact of this movement depending on the evolution of energy prices. The traditional centers (and here particularly Europe and Japan) may, however, not be threatened on all markets; the range of derivatives of ethylene produced from ethane is more limited than that produced by naphta cracking. It remains that the current scenarios are based on a reduction of market shares of the traditional centers, which is going to raise problems of excess capacities, which already exist in Europe and Japan.

On ethylene alone, Japan and Western Europe had an excess capacity of 20% in 1981-1982*, and the USA had an excess capacity of 25-35% in the same period. The European capacities had increased in the 1970s, and decreased somewhat at the beginning of this decade (+39% between 1974 and 1981, -18% between 1983 and 1981). For Japan the capacities have not evolved since 1979 after a 20% increase between 1974 and 1979; the US capacities increased strongly between 1974 and 1980 (+52%), and stayed around the 1980 level, with some fluctuations, until 1983. On the whole, the excess capacities have increased in all three centers, but more for Japan and Europe, where they already existed at the demand peaks of 1974 and 1979 (20% excess capacity against 4 to 8% for the USA).

DETERMINANTS OF ENERGY CONSUMPTION

Since no detailed analysis of the energy consumption of the sector is possible, we have tried to isolate a few "basic" chemical products, and to estimate their share in the total energy consumption with the help of energy coefficients taken from engineering studies, and to estimate the link between total energy consumption and the share of these products in the sector. This follows the same methodology as was used in previous case studies [5, 6].

Primary products, such as ethylene, propylene, butadiene, benzene, methanol, toluene, xylenes, acetylene, carbon black, soda, chlorine, ammonia, are considered as "basic" products; they have been chosen because: a) they are the most energy-intensive products, b) there are some studies [7, 8] available which estimated their possible specific energy requirements, and c) they minimize the risk of double counting. One must bear in mind that in this sector joint production is characteristic of most processes and that the existence of several 'routes' makes it difficult to estimate the specific energy requirements of a product. Here the risk of double counting is minimized, it is limited to the cases of joint production of olefins (ethylene, propylene, butadiene, butylene) and aromatics (xylenes, benzene, toluene). The major primary products of petrochemicals are considered here: olefins, aromatics, acetylene, methanol, ammonia, and carbon black, and the main basic products of inorganic chemicals: sulphuric acid, caustic soda, chlorine and fertilizers, the latter being taken not for their specific energy intensiveness, but because of their important tonnage.

The approach taken was to consider the most important chemical products in terms of tonnage with which energy intensities could be associated, and not to concentrate on a specific stage of chemical processing. A rough classification of products is given in Table 2.

*Source: OECD [1].

Table 2. Primary, intermediary, and final products

Primary	Intermediary	Final
Ethylene	Ethylene oxide	Plastics
Butadiene	Vinyl chloride	Sulphuric acid
Butylene	Styrene monomer	Fertilizers
Acetylene		
Benzene		
Toluene		
Soda		
Ammonia		

STRUCTURE OF THE INDUSTRY

Despite the short time span for which energy data are available, it is possible to observe changes in the structure of the chemical sector.

First, it must be stated that if all of the countries considered here produce nearly all of the commodities considered, they do not have the same relative shares of all products. This results from the particular historical development of the sector in each country, and could also be the consequence of the feedstock structure: the range of products obtainable from methane is not as large as that from oil, and Europe has an oil-dominant feedstock structure, as opposed to the USA, where gas is dominant.

Some products come from the same cracking operation, and therefore have linked production, such as ethylene and propylene (Table 3).

Table 3. Ratio of ethylene production to propylene production

	FRA	FRG	ITA	SPA	SWE	UK	USA
1977	2.00	1.95	1.70	1.92	2.23	1.72	1.91
1982	1.92	1.78	1.96	2.12	2.80	1.40	2.01

The ratio is around 2 for every country, but there are some variations over time (it drops as low as 1.4 for the UK in 1982) and across countries (Sweden has a higher ratio, systematically over 2, rising as high as 2.8, whereas the UK has a low ratio).

Such differences are more important for other petrochemicals (Table 4). Porudction figures of various commodities

Table 4. Production ratios between petrochemicals

		FRA	FRG	ITA	SPA	SWE	UK*	USA
ethylene / butadiene	77	7.37	3.07	7.62	7.35	3.67	5.13	2.01
	82	7.14	2.31	5.48	9.41	3.97	4.61	1.65
ethylene / acetylene	77	127.8	14.7	8.6	12.6	55.2	n.a.	61.4
	82	161.8	14.1	23.9	175.8	79.7	n.a.	80.0
ethylene / ammonia	77	0.92	1.50	1.03	0.27	2.28	n.a.	0.86
	82	1.11	1.68	0.68	1.03	2.47	n.a.	0.97
ethylene / carbon black	77	11.05	9.91	8.91	5.71	9.90	5.54	7.28
	82	10.66	7.59	5.75	12.17	9.43	6.56	8.93
ethylene / methanol	77	5.00	3.37	6.08	4.33	31.90	n.a.	3.94
	82	5.36	3.72	9.76	7.48	157.17	n.a.	3.40

*surprisingly, no data are available for the U.K.

are compared to those of ethylene, the main petrochemical product, and they are expressed as the ratio between ethylene production and the production of the commodity considered: the larger the ratio, the smaller is the production of the commodity compared to that of ethylene.

One may particularly notice the difference in the ratios between ethylene production and the production of less energy-intensive products, such as carbon black and methanol, or that of a more energy-intensive product than ethylene, such as actylene.

There is no simple comparison across countries concerning these ratios. Despite having similar feedstock structures, European countries may have important differences in the production ratio (butadiene or acetylene). The USA is generally different from Europe, and Spain and Sweden are special cases considering the size of their industries. Over time there may be important changes such as the spectacular decrease of the Spanish acetylene production relative to ethylene (as well as in absolute terms, see Table 6) or the decrease of the Swedish methanol production, or at least noticeable changes, such as the decrease of the acetylene production in France, of carbon black in Spain, of methanol in Italy, or the increase of the carbon black production in the FRG, of butadiene in Italy or in the USA. Thus, in spite of the strong links in petrochemical production, the production structure is not as rigid as to forbid changes in the product mix that could influence the industrial energy consumption.

It may then be misleading to take into account only ethylene as a petrochemical product; indeed, it would be better to expand the list of products beyond those that are generally looked at in special studies such as the OECD study [1].

The decrease of the energy coefficient is far from being general; for France we get an inverted U-curve with a growth until 1979, followed by a drop in 1980 and since then stagnation around the 1977 level. Sweden shows approximately the same behavior of its coefficient. For other countries the decrease of the coefficient is approximately regular; for Italy it is -4% p.a. and for the UK -2% p.a. The FRG has a constant coefficient until 1979 and a steep decrease after 1980; Spain followed the same pattern but with a smaller decrease after 1980; the US decrease was limited until 1980, when it apparently accelerated (the energy figure for 1982 is missing). A simple explanation could lie in the differential growth of different subsectors of the industry: France has got a faster growth of basic chemicals than of other chemical products (SIC 351 and SIC 352, respectively), whereas this is the opposite for other countries, and particularly for Italy. On the whole, the evolution of the energy coefficient is linked to the differential of growth between the two subsectors. But even within the basic chemicals sector (SIC 351) some differences may explain the evolution of the (aggregated) energy coefficients in Table 5. It appears that France experiences a larger growth of energy-intensive primary commodities than the other countries*: this applies to ethylene, propylene, and butadiene. Italy shows the opposite curve: production of these petrochemicals decreases sharply, propylene production is cut by half, ethylene by 40%, even inorganic basic products decrease. The other countries lie inbetween, with a general decreasing trend, the product mix changing somewhat. Table 6 shows the production indices of a few commodities, and indicates growth or decrease in absolute terms. The results of this table can be checked with those of Table 4, where the production figures are compared to ethylene, showing the relative increase or decrease of production.

To estimate more accurately changes due to product mix, we will calculate the impact of the most energy-intensive products with engineering data.

So-called 'engineering data' can be found in the literature on energy economics. One may distinguish three types of publications: a) books whose aim it is to present an analysis of the energy consumption from an engineering point of view, and which look into various products and processes to isolate some energy coefficients (these are books like that of I. Boustead and G.F. Hancock [9]); b) there are books which focus on the industry of a particular country (generally the USA), and which give a more complete analysis of the industrial

*Except for Spain, whose petrochemical sector is developing rapidly.

system (these are books such as that of Oak Ridge Associated Universities [10]); and c) there are specific sectoral studies from an energy point of view, which are generally made by international organizations ([1,7,8]). All this literature gives energy coefficients on which our estimates are based (Table 7).

Table 5. Energy coefficient indices* (1977 = 100)

	FRA	FRG	ITA	SPA	SWE	UK	USA
1977	100	100	100	100	100	100	100
1978	108	99	94	96	107	96	96
1979	111	102	93	102	111	97	97
1980	100	91	89	98	91	89	96
1981	104	89	84	88	88	94	86
1982	99	85	82	89	89	90	n.a.

*Energy coefficients are calculated as the ratio of two indices, one for energy consumption (in physical units), and another for industrial production taken from UN statistics.

Table 6. Production indices of some commodities in 1982 (1977 = 100)

	FRA	FRG	ITA	SPA	SWE	UK	USA
Ethylene	117	88	62	225	101	95	97
Propylene	121	96	54	203	81	117	92
Acetylene	92	92	22	16	70	n.a.	75
Chlorine	103	101	72	98	88	85	86
Ammonia	97	79	93	60	79	n.a.	86

Table 7. Energy coefficients (GJ/t)

Ethylene	60-80	Carbon black	15-30
Propylene	60-85	Sulphuric acid	0.5-10
Butadiene	70-100	Soda	20-40
Benzene	60-70	Chlorine	10-25
Methanol	40-55	Ammonia	20-50
Toluene	60-80	Fertilizers	5-10
Xylenes	60-80		
Acetylene	70-100		

The coefficients generally lie within a narrow range*, with the exception of fertilizers, but this depends on whether the figures refer to direct or total energy requirements. The total energy requirement for fertilizers is high because of their raw material composition (nitrogen, ammonia), whereas the direct energy input seems to be rather low.

When we take an average value as energy coefficient and apply it to the production figures of the commodity concerned, the estimated share of basic products (s) in total energy consumption of the sector is as given in Table 8**.

Table 8. Share of basic products in total energy consumption (%)

	FRA	FRG	ITA	SPA	SWE	UK	USA
1977	60	55	48	38	56	28	78
1982	70	63	41	43	51	32	82

The share of the UK is surprisingly low, partly because there are no production figures for methanol, xylenes, soda, and ammonia. The US figure is higher than the others, but this may be explained by the fact that the total energy consumption figure does not come from the same source as for the other countries, but is based on the US census of manufactures, and may thus be underestimated compared to the actual figure. For the other countries it appears that the estimated share of basic products is between 40 and 70% of the total energy consumption, and that the production of these few products has therefore a large impact on the energy consumption of the sector.

Table 9 and Figure 1 show that the energy coefficient (total energy consumption/value of output) and the restricted energy coefficient (estimated energy consumption of the chemical products chain ("s"/value of output)) are related. It may be noted that the position of two countries could be corrected: first, the UK should be moved upwards, since "s" is clearly underestimated, and second, the US should be moved to the right, since the energy consumption reported in Doblin [12] is probably underestimated. Figure 1 may be used to

*Differences in energy requirements may also result from the different routes used, as shown in the ECE study: ammonia production from natural gas requires 40 GJ/t, and 90 GJ/t from low grade coal.

**Figures on total energy consumption for Europe are taken from CEFIC [11], and from Doblin for the USA (reconstruction of total energy inputs based on the US census of manufacture) [12].

interpret the specialization of each country's chemical sector; a higher energy coefficient goes with a higher share of energy-intensive commodities. Apart from the USA and the UK, the position of Italy may also be explained by exchange rate effects, and may be nearer to those of the other European countries (FRG, France), which are more closely grouped together.

Table 9. Energy coefficients (in tce/1000 US $)

	FRA	FRG	ITA	SPA	SWE	UK	USA
Energy coefficient (enco)	0.92	0.84	1.4	1.33	0.91	0.98	1.03
Sum/output* (sco)	0.55	0.47	0.68	0.50	0.51	0.28	0.80

*The "sum" is the estimation of the energy consumption due to the production of the basic chemicals taken into account here.

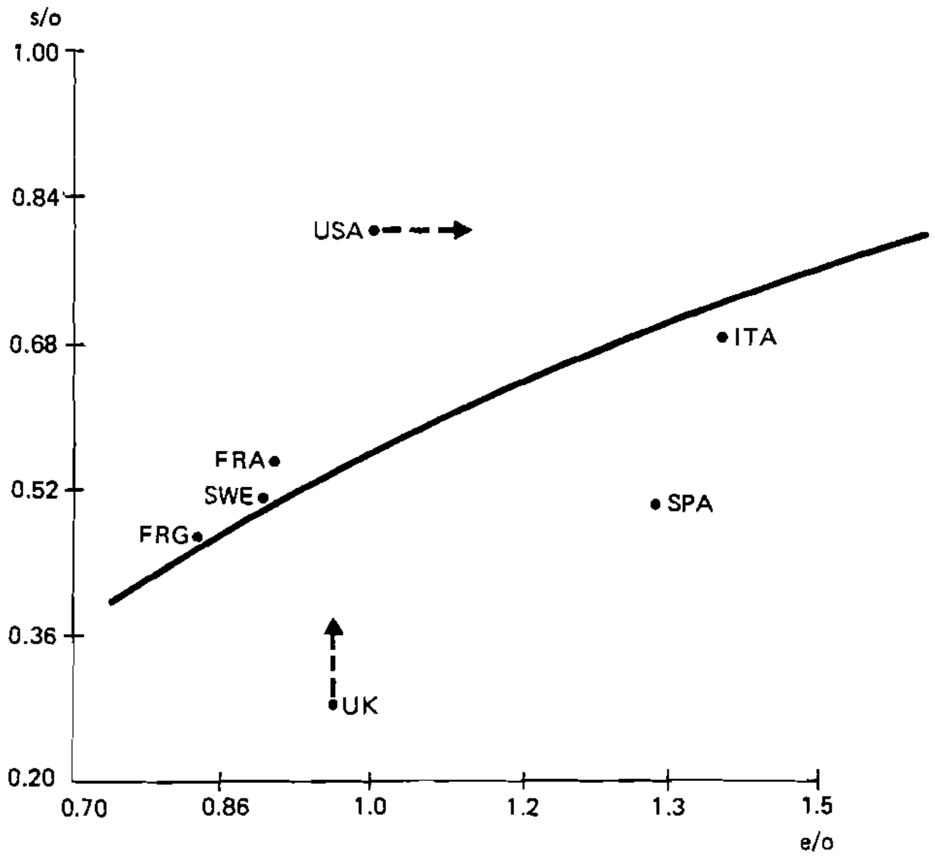

Figure 1. Energy coefficients for the year 1980.

The link between the energy coefficient and the coefficient defined as the ratio between the consumption due to the production of basic chemicals and the total output of the sector (both coefficients given in (1970 = 100) indices) can be more precisely determined. With the help of econometric relations we have tested whether there is a relationship between the sector's energy demand (either as such or as a coefficient) and the energy consumption due to the energy-intensive commodities. Time trends are also introduced as variables, expressing a decrease not linked to the production of the commodities mentioned above. For the pooled sample of the seven countries this gives for the period of 1977-1982:

$$\text{(1)} \quad enco = \underset{(7.2)}{32.9} + \underset{(14.7)}{0.69}\ sco - \underset{(-12.0)}{2.47}\ t246 - \underset{(-3.3)}{1.03}\ t1 - \underset{(-8.5)}{1.47}\ t7$$

$$R^2 = 0.99 \qquad \Sigma e^2 = 5611$$

The t's refer to time trends for each country, the numbers refer to the countries: 1 for France, 2 for the FRG, 3 for Italy, 4 for Spain, 5 for Sweden, 6 for the UK, and 7 for the USA.

The introduction of sco gives a better regression than simply using time trends.

$$\text{(2)} \quad enco = \underset{(106.8)}{103.2} - \underset{(-9.0)}{2.7}\ t267 - \underset{(-7.3)}{3.62}\ t3 - \underset{(-3.0)}{1.94}\ t4$$

$$R^2 = 0.99 \qquad \Sigma e^2 = 16770$$

The time trends are furthermore different themselves; e.g. the decline of the Italian coefficient is entirely due to the decline of the share of the chosen products in total energy consumption*, and the time trend in equation (2) disappears in equation (1) when sco is introduced. The opposite could be said for France: the apparent steadiness of the energy coefficient is entirely due to the production of the energy-intensive products.

The same applies when we use total energy inputs instead of coefficients (equations (3) and (4)).

$$\text{(3)} \quad e = \underset{(2)}{12.6} + \underset{(15.9)}{0.74}\ s + \underset{(2.5)}{0.16}\ ing - \underset{(-6.4)}{1.54}\ t17 - \underset{(-11.4)}{2.5}\ t246$$

$$R^2 = 0.99 \qquad \Sigma e^2 = 6574$$

*See Figure 1, which manifests a higher degree of specialization on our sample of products.

(4) $e = 24.2 + 0.79\ s - 1.36\ t17 - 2.61\ t246$
$(5.5)\quad(17.8)\quad(-5.51)\quad(-11.0)$
$R^2 = 0.99 \qquad \Sigma e^2 = 7724$

It can be seen that the determination of energy inputs is better when we take into account the impact of the production of the energy-intensive products than when we simply relate the energy consumption to an index of activity (ing) as is shown in equations (5) and (6).

(5) $e = -3.8 + 1.07\ ing - 3.3\ t237 - 2.2\ t46$
$(-0.3)\quad(9.6)\quad(-8.2)\quad(-4.7)$
$R^2 = 0.99 \qquad \Sigma e^2 = 20740$

(6) $e = 1.03\ ing - 3.2\ t237 - 2.3\ t46$
$(99.2)\quad(-9.2)\quad(-4.9)$
$R^2 = 0.99 \qquad \Sigma e^2 = 20802$

Since some products were missing for the United Kingdom, the values of s and sco for this country are underestimated. If we drop the UK from the sample, one can see that the advantage of our approach is not altered:

UK Excluded

(1') $enco = 30.4 + 0.72\ sco - 1.11\ dt1 - 2.44\ t24 - 1.74\ dt7$
$(6.5)\quad(14.8)\quad(-3.5)\quad(-10.8)\quad(-8.4)$
$R^2 = 0.99 \qquad \Sigma e^2 = 4633$

(2') $enco = 103.6 - 2.18\ t27 - 3.68\ dt3 - 1.99\ dt4$
$(97.8)\quad(-8.3)\quad(-7.0)\quad(-2.9)$
$R^2 = 0.99 \qquad \Sigma e^2 = 15621.8$

(3') $e = 23.6 + 0.80\ s - 1.39\ t17 - 2.46\ t24$
$(5.1)\quad(17.0)\quad(-5.5)\quad(-9.2)$
$R^2 = 0.99 \qquad \Sigma e^2 = 6091$

(4') $e = 12.7 + 0.76\ s + 0.13\ ing - 1.56\ t17 - 2.51\ t24$
$(1.8)\quad(15.9)\quad(1.99)\quad(-6.09)\quad(-9.73)$
$R^2 = 0.99 \qquad \Sigma e^2 = 5384$

$$(5')\quad e = -4.4 + 1.08\ ing - 3.4\ t237 - 2.3\ dt4$$
$$\qquad (0.3)\quad (8.3)\qquad (-7.4)\qquad (-2.8)$$
$$R^2 = 0.99 \qquad \Sigma e^2 = 19729$$

$$(6')\quad e = 1.04\ ing - 3.3\ t237 - 2.2\ dt4$$
$$\qquad (90.0)\qquad (-8.6)\qquad (-2.9)$$
$$R^2 = 0.99 \qquad \Sigma e^2 = 19799$$

The energy consumption of the whole chemical sector is then heavily dependent on the production of a few energy-intensive basic chemicals, and it may be correct to assume that a relocation of the world's petrochemical industry, which greatly reduces the production of the traditional centers, will change the consumption pattern of the sector. A permanent relocation of heavy activities away from Europe or Japan, and a specialization of these centers on fine chemicals, or more generally in processed products, is likely to lower the energy consumption considerably. This trend has already been observed for the USA [12], where chemical imports are rising, mainly because of a higher import demand of basic (energy-intensive) chemicals, generating energy 'savings' of about 5%. An estimation of the possible savings due to a reduction of basic chemical production should also take into account the effect of housekeeping measures (which, according to OECD, may save up to 15% energy, and these effects are clearly within our trend estimates of 1.5 to 3% per year), as well as the effect of excess capacity and plant closures.

The use of engineering data could be extended to long-term forecasting of energy consumption; making assumptions on the production of a few energy-intensive commodities would help to deduce associated energy demand and, subsequently, the sectoral energy consumption.

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