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BREAKING THE ENERGY COEFFICIENT: CROSS-COUNTRY ANALYSIS FOR THE IRON AND STEEL INDUSTRY

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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 provides 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 most 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
Project Leader
Comparative Analysis of
Economic Structure and Growth

BREAKING THE ENERGY COEFFICIENT: CROSS-COUNTRY ANALYSIS FOR THE IRON AND STEEL INDUSTRY

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INTRODUCTION

This paper examines energy consumption in the iron and steel sector in six major Western countries (United States, Japan, France, the FRG, Italy, and the United Kingdom) in relation to changes in the production structure of the industry. As far as national energy consumption is concerned, the iron and steel sector plays an important role: being an energy-intensive sector, its share in total industrial energy consumption is generally high (see Table 1), and the sector itself is usually the first or second largest (after chemicals) industrial energy consumer; within the sector, energy costs represent between 20 and 60% of production costs at each stage of production ([3]).

Table 1. Share of energy consumption of the iron and steel sector in total industrial energy consumption (%), 1970-82.

	USA	JAP	FRA	FRG	ITA	UK
1970	17.2	36.1	24.7	32.8	16.9	26.0
1975	16.4	39.4	24.5	31.7	17.3	20.3
1982	10.4	31.8	15.8	23.6	20.3	16.2

Source: [1].

The first part of the paper reviews the determinants of energy consumption in the iron and steel industry, focusing on changes over time in steel-making processes. The second part describes an econometric study of the role played by the factors identified in Part I in the decrease of the energy coefficient.

I. DETERMINANTS OF THE EVOLUTION OF ENERGY CONSUMPTION IN IRON AND STEEL PRODUCTION

1. Data Sources

The energy consumption figures (in millions of tons of oil equivalent) are taken from the 'OECD Energy Balances 1970-1982'. The OECD data provide sufficiently coherent time series for a cross-country analysis, even if figures in absolute terms differ from those given in national energy balances, mostly because of conversion coefficients and different accounting practices. The energy figures express the net energy consumption of the sector; conversion losses in coking and production of blast-furnace gas and coke-oven gas are not included in iron and steel energy consumption.

The figures concerning steel production are taken from the UN Quarterly Bulletin of Iron and Steel, sometimes from the OECD annual publication 'The Iron and Steel Industry', or from various national sources, since differences between sources are generally negligible. The production of crude steel is measured in thousands of metric tons, with corresponding figures for each separate process: open-hearth, oxygen, electric, and continuous-cast.

The energy coefficient chosen is defined as follows:

$$\frac{\text{sectoral energy consumption}}{\text{total production of crude steel}}$$

in units of toe/metric ton of crude steel.

The production of crude steel is the indicator of activity considered, although it does not itself represent the final stage of the iron and steel industry. Since this paper deals mostly with changes in production processes rather than with changes in demand, it seems better to refer to crude steel throughout. Moreover, crude steel is a homogeneous product, whereas it is difficult to add up the products of different stages of processing into one coherent finished-products indicator. There have been no great differences in the historical evolution of the production of crude and finished steel,* though there have been some differences across countries, depending on productivity, imports or exports of crude steel, etc.

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*In volume terms.

The ratios of rolled products to crude steel in 1978 for the six countries studied were as follows:

USA	JAP	FRA	FRG	ITA	UK
.72	.90	.90	.85	.74	.81

Source: [2].

The energy requirements for finished steel only do not represent more than 20% of the total energy requirements of the sector, as shown in Table 2.

Table 2. Direct energy inputs at different stages of production as percentages of total energy use, 1980.

Country	Ore preparation, agglomeration, & pig iron production	Crude steel production	Rolled products & tubes	Other uses	Total
Japan	61.51	8.43	14.94	15.12	100.00
France	67.79	6.84	14.47	10.90	100.00
FRG	61.70	7.19	14.58	16.53	100.00
Italy	39.17	17.19	21.43	22.23	100.00
UK	46.43	11.21	18.03	24.33	100.00

Source: [3].

2. Steel Production

The six countries studied each have a total annual steel production in excess of 10 million tons, while Japan and the United States are, respectively, the first and second largest Western steel producers (Table 3). The evolution of production across countries has, however, been rather different.

Table 3. Production of crude steel (in million tons), 1970-82.

Year	USA	JAP	FRA	FRG	ITA	UK
1970	119.140	93.322	23.773	45.041	17.277	28.316
1982	66.137	99.548	18.402	35.880	24.009	13.697

Only Japan and Italy increased their production between 1970 and 1982, while there was a marked decrease for all the other countries, particularly for the United States and the

United Kingdom. The 1970s witnessed a severe crisis in the iron and steel sector on a world level, and each country experienced some consequent decreases in production. Around 1974-75, every country experienced a recession, while some had had one even earlier (Japan (1973), FRG (1971)); after 1975, neither Japan nor Italy saw a fall in their respective production of crude steel, except for a slow decrease after 1979 for Japan. For the other countries, 1980-82 was a period of crisis, with US production decreasing by 38%, and UK production by 48%. The recent evolution of the industry in each country is summed up in Table 4.

Table 4. Dynamics of steel production by country, 1970-82.

Parameter	USA	JAP	FRA	FRG	ITA	UK
Change in level of production between 1970 and 1982 (%)	-44.5	+6.7	-22.6	-20.8	+39.0	-51.6
Peak year during the period	1973	1973	1974	1974	1980	1970
Lowest year during the period	1982	1971	1982	1982	1970	1982
Difference between peak year and 1982 level (%)	-50.6	-19.8	-31.0	-32.6	-9.4	-51.6

Japan and Italy are the two exceptions, with the four other countries following essentially the same trend: peak production occurred before the first oil shock and the lowest year was 1982. The United Kingdom is the most extreme example of this trend, with a decrease throughout the period. Italy's experience was exactly opposite to that of the United Kingdom: there was a more or less continuous increase of production, in contrast with all the other countries studied, including Japan.

3. Technological Changes

Changes in the iron and steel sector during the period studied were mainly twofold:

- In final products, developments in the industrialized countries seemed to center on "flat" or pressed products such as steel plates for cars, and in general on products with a greater proportion of value added. Competitive "long" (extruded or drawn) products were generally made out of electric steel, and are not examined in this paper.

- In the steel production itself, new processes were introduced (electric steel, continuous casting), whose result has been to increase the general productivity of the sector, and especially its energy productivity.

These two domains are not totally separated, for the evolution of end-use influences the evolution of technologies; the increase in the market shares of high-value-added products made necessary the introduction of up-to-date technologies through the whole steel-making process.

There are several ways of making steel, each having different energy requirements at different stages. The most traditional method is via pig iron. Iron ore is prepared and agglomerated, then melted with coke in blast furnaces to produce the pig iron. The further treatment of the pig iron may be either in open-hearth or in basic oxygen furnaces. An alternative way of producing steel is through the recovery of scrap, melted in electric furnaces. The oxygen process can also use a certain proportion of scrap (up to 30%) depending upon its quality and availability, while the open-hearth process generally uses less than 10% scrap.

The energy requirements for steel making itself, according to the process used, are given for four of the countries in Table 5 ([3]).

Table 5. Direct energy input per ton of crude steel (toe/t), 1980.

Country	Oxygen	Electric-arc	Open-hearth
Japan	.0173	.1398	not applicable
France	.0220	.1584	.2580
FRG	.0242	.1523	.0722
Italy	.0183	.1476	.1321

Generally speaking, the electric-arc process is the most energy-intensive in terms of direct energy use; but when the whole process of steel making is considered, the electric-arc route turns out to be least energy-intensive overall, since it requires scrap instead of pig iron. The production of pig iron is the most energy-intensive operation within the steel-making industry, as shown by Table 2 and the data below on direct total energy use in ore agglomeration and pig iron production in 1980 (toe/t):

France	Italy	FRG	Japan
.5487	.4439	.5020	.4399

Source: [3].

Ore agglomeration and pig iron production account generally for two-thirds of the total energy requirements for steel making.

The oxygen process is less energy-intensive than the open-hearth (or "Martin") process. This latter process uses electricity and requires no thermal energy* since the reaction is exothermal.

Apart from changes in the steel making itself, the main technological innovation has been continuous casting, which involves treating the steel directly as it emerges from the furnaces and thus avoids the intermediate production of steel ingots and consequent reheating before further processing. The process not only saves energy, but increases the yield: this is between 94 and 99 percent in continuous-cast plants, which is 10 to 12% higher than the figure for ordinary mould-casting methods.

We may then isolate three factors concerning steel making and one factor concerning steel processing that significantly influence the energy consumption of the sector:

- the share of each process--Martin, oxygen, and electric--in steel making
- the share of continuous-cast products in total production.

The share of continuous-cast products is also an indicator of the general 'efficiency' of the sector, since this method has only been introduced in the most modern plants.

The share of the Martin (or open-hearth) process provides an indicator of the 'energy efficiency' of the sector but only for the earlier part of the period 1970-82, because the process itself nearly disappeared after 1978-79 except in the United States. It will be interesting to consider it later as an indicator of 'efficiency' for the base year 1970, and to use the two other processes to explain the evolution over time of energy consumption.

Important changes in the structure of the iron and steel sector have taken place between 1970 and 1982. Developments in the shares of the three main processes are shown in Table 6.

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*See B. Chateau and B. Lapillonne, Energy Demand: Facts and Trends. Springer-Verlag, Vienna and New York, 1982 [6].

Table 6. Structure of crude steel production by process (%), 1970-82.

	Open-hearth						Oxygen						Electric-arc					
Year	USA	JAP	FRA	FRG	ITA	UK	USA	JAP	FRA	FRG	ITA	UK	USA	JAP	FRA	FRG	ITA	UK
1970	36.3	3.4	60.2	34.4	28.0	48.4	48.2	79.6	28.9	55.8	31.5	32.1	15.3	17.0	10.9	9.8	40.5	19.5
1975	19.0	0.8	22.5	18.1	11.2	22.1	61.6	82.2	63.5	69.3	45.8	50.3	19.4	17.0	14.0	12.6	43.0	27.6
1978	15.6	-	6.7	10.9	5.4	8.8	60.9	77.7	78.2	74.6	43.5	55.8	23.5	22.3	15.1	14.5	51.1	35.4
1982	8.2	-	1.0	1.5	1.3	-	60.7	72.5	80.1	80.9	47.4	66.1	31.1	27.5	18.9	17.6	51.3	33.9

Source: [2].

In 1970, the open-hearth process* had the dominant share in France, but oxygen soon took over this position (1975), while electric-arc exhibited a slow and regular increase. The FRG had, in 1982, a production structure very similar to that of France, but the oxygen process was still important in 1970. The only significant changes for Japan concerned the increasing share of electric-arc; in 1970, open-hearth was marginal and oxygen dominant, and Japan is the only country where this latter process later declined. The general movement (decline of open-hearth and rise of oxygen) was weaker in the United States but the increase of electric-arc was relatively stronger.

The decline of open-hearth in the United Kingdom was slower until the end of the 1970s than for the other countries, but the share of electric-arc was more important than in other European countries, since both its level and development over time were comparable to those recorded in Japan. Italy has a fairly unique production structure: the share of electric steel has always been much higher than in other countries and it has been the major process since 1978, although its share has tended to stagnate somewhat recently. As a consequence, the share of the oxygen process in Italy is somewhat lower than in the rest of Europe; however, even in 1970 the open-hearth process had a lower share than oxygen.

The introduction of continuous casting was the other major technological change during the period (see Table 7).

Table 7. Share of continuous cast steel in total steel production (%), 1970-82.

Year	USA	JAP	FRA	FRG	ITA	UK
1970	n.a.	6.9	0.8	8.3	4.2	1.8
1975	9.1	32.8	10.2*	19.4*	n.a.	5.0*
1978	15.2	48.3	n.a.	38.0	n.a.	15.4
1982	26.9	82.7	58.5	61.9	58.5	39.0

*1974 data.
n.a. means not available.

Sources: [2], [4].

The United States was perceptibly slower in adopting continuous casting than the other countries; conversely, Japan

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*In fact the Thomas and Bessemer shares are also included in this figure. In this paper the open-hearth share represents the share of all processes other than electric-arc and oxygen. Out of the countries studied, Thomas and Bessemer processes are only found in France.

witnessed a very rapid growth of this process. The United Kingdom was slower in adapting than other ECSC* countries.

4. Energy Consumption

As we have seen in Section 3, the evolution of technologies in each of the six countries was quite different; considering the impact of technological change on energy consumption, it is therefore not surprising that we found different absolute levels of the energy coefficients and different rates of evolution for these coefficients (see Table 8).

Table 8. Energy coeffcients (toe per ton of crude steel), 1970-82.

Year	USA	JAP	FRA	FRG	ITA	UK
1970	.5924	.4674	.5818	.5624	.4185	.6130
1971	.6198	.4899	.5604	.5732	.4292	.6442
1972	.5878	.4340	.5492	.5528	.3618	.5767
1973	.5572	.4274	.5514	.5493	.3677	.5731
1974	.5684	.4442	.5418	.5452	.3693	.5631
1975	.5912	.4559	.5588	.5943	.3618	.5803
1976	.5398	.4294	.5293	.5161	.3493	.5347
1977	.5267	.4287	.5368	.5099	.3343	.5355
1978	.4938	.3817	.5249	.4402	.3492	.5111
1979	.5077	.3773	.4658	.4277	.3485	.5269
1980	.5791	.3914	.4574	.4425	.3173	.5808
1981	.4568	.3619	.4328	.4223	.3265	.4912
1982	.5468	.3792	.3891	.4281	.3199	.5045
change (%) between 1970 and 1982	-7.7	-18.8	-33.1	-23.9	-23.6	-17.7

Sources: [1], [2].

A first glance at the energy coefficients reveals a general trend as well as many ups and downs. Capacity utilization is of great importance in explaining these latter variations. Many authors (e.g. [5]) insist on the effects of declining capacity utilization in most industries on levels of energy consumption. In the case of iron and steel, energy consumption decreases less than production, due to the existence of a "fixed" component of energy consumption whatever the

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*European Coal and Steel Community.

level of production, unless plants are actually closed; the pattern of plant closures is not the same as the pattern of decrease in production, and in any case capacities cannot be adjusted instantly to new conditions. This explains fluctuations in the figures from one year to another, independent of the general trend.

Insofar as cross-country comparisons are possible, the levels of energy coefficients were already very different in 1970, and subsequent developments have widened these differences still further. In 1970 Japan and Italy formed a group distinct from the United States, the United Kingdom, France, and the FRG, with a much lower energy coefficient; the manufacture of one ton of crude steel required 24% less energy in Italy than in the United Kingdom. In 1982, one ton of Italian steel required 42% less energy than one ton of American steel.

In 1970, Italy and Japan had the lowest share of the open-hearth process, Italy had a high share of electric arc, and Japan had a 'modern' production structure with a high share of oxygen steel. France has witnessed the most marked decrease in its energy coefficient, and has also been the country where the productive structure has altered the most during the period: in 1970 the open-hearth had almost completely disappeared, the share of continuous-cast steel was comparable to that of Italy and the FRG, and there was a strong increase in the share of electric steel. The FRG and Italy are comparable as regards the evolution of their energy coefficients as well as their production structures. The difference in the absolute levels of the coefficient may be explained by the role of electric steel in Italy. Despite the disappearance of the open-hearth process and the relative importance of electric steel, the United Kingdom has not witnessed any important decrease in its energy requirements per ton of steel produced; this may be a consequence of the slower introduction of continuous casting. As the production structure of Japan was already 'modern' in 1970, the only major changes since then have concerned electric steel and especially continuous casting, which resulted in a decrease of 19% in the energy coefficient between 1970 and 1982.

Different steps can be identified in the decrease of energy coefficients for each country. The major downward changes occurred in 1977 for Japan, in 1976, 1979, and 1982 for France, in 1976 and 1978 for the FRG, in 1972 and 1980 in Italy, and in 1972 and 1976 for the United Kingdom. The years of recession saw an increase of the energy coefficient in most countries (for the United Kingdom in 1980, for the FRG in 1975, etc.). The effects of the two oil shocks do not appear clearly from a first inspection of the energy coefficients; only for France, the FRG, and the United Kingdom was a major change observed in 1975, and only France and Italy recorded such a change at the end of the 1970s. However, these effects should not be underrated because of the particular importance of energy in steel production costs; the new energy-supply conditions have influenced the evolution of the steel industry, making electric steel more attractive, and generally underlining the importance of energy control in this sector.

To sum up, we may conclude that the changes in the processes used for steel making seem to be the main determinants of the decrease in the energy coefficient. The share of the open-hearth process, especially at the beginning of the period, the relative importance of electric steel, and the more or less rapid introduction of continuous casting have all played important roles in the energy requirements of the iron and steel sector, whose development is illustrated in Figure 1 for each country over the period considered.

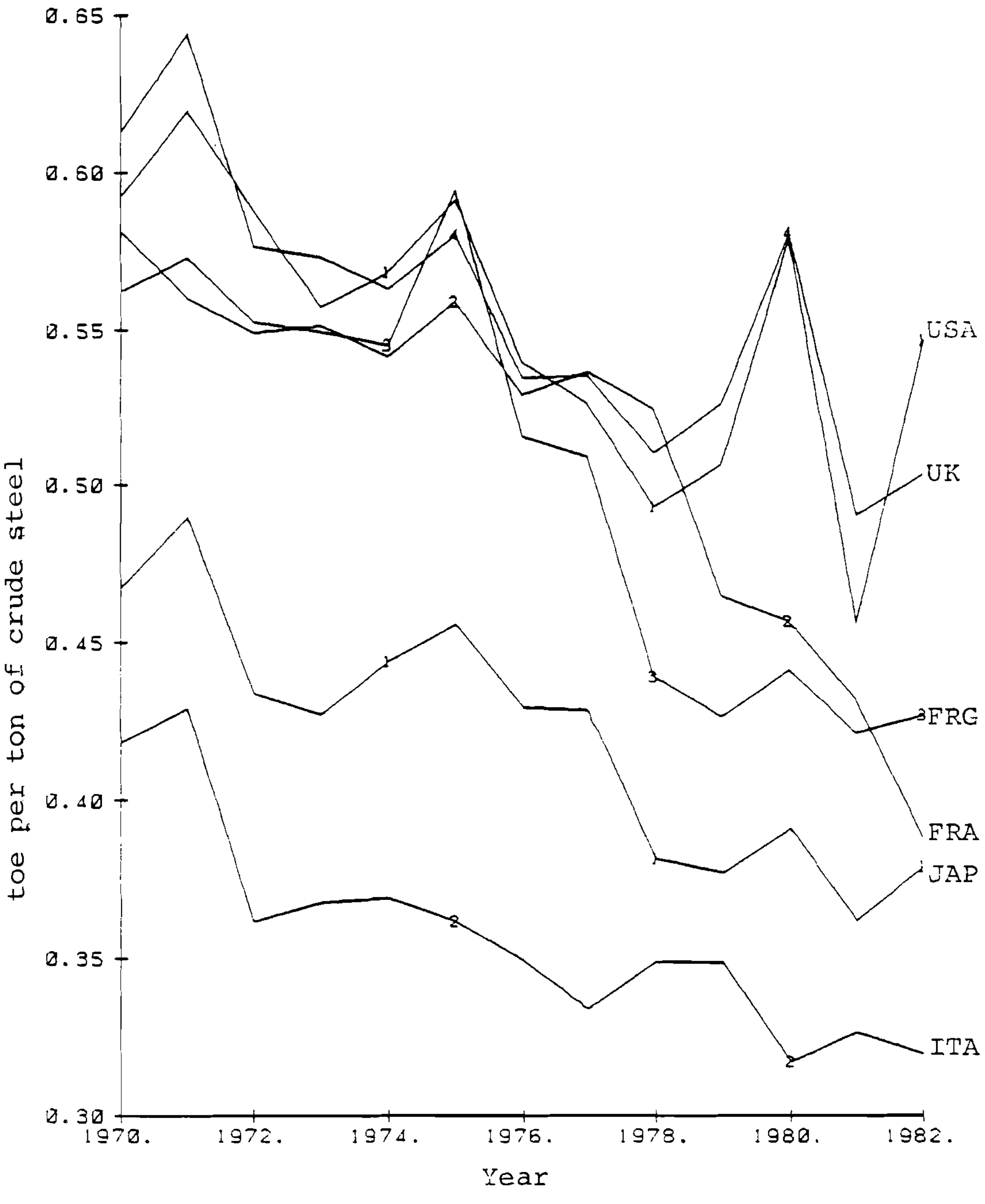

Figure 1. Evolution of the energy coefficients of the six countries.

II. THE ECONOMETRIC ANALYSIS

An econometric analysis of cross-sectional data for the six countries studied has been performed in order to explain the variance among energy coefficients in terms of the shares of two major processes, the Martin (or open-hearth) and the electric-arc, in the 1970s. As we have seen in Part I, countries with a higher share of the Martin process have a higher energy coefficient than those countries where Martin steel making is less important, because of the physical and chemical characteristics of the process.

The basic equation used in the analysis is as follows:

$$e_i = \alpha + \beta S_{mi} + \gamma S_{el_i} + \varepsilon_i$$

where

i = country index

e_i = energy coefficient for country i

S_{mi} = share of Martin process for country i

S_{el_i} = share of electric process for country i

ε_i = error term.

Since the sum of the production from the Martin, electric, and oxygen processes equals total steel production, there is no need to introduce the third (oxygen) process explicitly in the equation. The regression results are consistent with both common sense and engineering data: the increasing share of electric-arc steel is certainly a factor in the decrease of the energy coefficient, while an increase in the share of Martin steel, a variable representing the stage of development of the industry, makes the coefficient bigger:

$$\begin{array}{l} e = .5037 + .24\ S_m - .36\ S_{el} \\ \quad\ \ (7.17)\quad (2.2)\quad\ \ (1.7) \\ R^2 = .7780 \end{array} \tag{1}$$

However, the parameter estimate for electric steel is not significant, and the bulk (57%) of intercountry variance is explained by the first factor:

$$\begin{array}{l} e = .4163 + .29\ S_m \\ \quad\ \ (7.4)\quad\ (2.3) \\ R^2 = .5712 \end{array} \tag{2}$$

This is understandable because the variance within this small sample in the electric-arc share was smaller than the variance in the share of the Martin process. On comparing the estimated results with the observed data (Table 9) it can be seen that regression 1 gives better results only for Italy; in this case it is necessary to introduce the share of electric-arc steel, which was between two and four times bigger in Italy than in the other countries studied (40% for Italy and 10-20% for the other countries).

Table 9. Actual and fitted values of the energy coefficient, 1970.

		Fitted	
Country	Actual	Regression 1	Regression 2
Italy	.4185	.4364	.5094
UK	.6130	.5647	.5744
Japan	.4348	.4573	.4284
FRG	.5624	.5765	.5474
France	.5818	.6282	.6148
USA	.5876	.5379	.5238

The regression may be interpreted in terms of energy requirements for each particular process:

We have

$$c = .5037 + 24\ S_m - .36\ S_{el}$$

Thus

$$\begin{aligned} e \text{ (steel production)} &= .5037 \text{ (oxygen steel + martin steel + electric steel)} \\ &+ .24 \text{ (Martin steel)} \\ &- .36 \text{ (electric steel)} \end{aligned}$$

and

$$\begin{aligned} \text{energy consumption} &= .5037 \text{ (oxygen steel)} \\ &+ .74 \text{ (Martin steel)} \\ &+ .14 \text{ (electric steel).} \end{aligned}$$

The coefficient for each process is thus the energy requirements of this process per ton of crude steel. Both the levels of the coefficients and the ranking of the processes are consistent with the results report in Part I (see Table 5).

The same regression cannot be used for the 1980s, since by then the Martin process had disappeared and the share of continuous-casting rather than electric-arc perhaps represented a more accurate indicator of the extent of modernization of the industry. Therefore we utilized the following equation when estimating and regressing the 1980s data:

$$e_i = \alpha + \gamma S_{el_i} + \delta S_{cc_i} + \varepsilon_i$$

where S_{cc_i} is the share of continuous casting in the total. The same procedure was applied to an energy coefficient e(1), corrected for the contribution of Martin steel in those countries where it still existed in 1982 (the United States):

$$e_i(1) = e_i - .24\ S_{mi}$$

The results for 1982 are in general consistent with engineering estimates and common sense:

$$\begin{array}{l} e = \underset{(9.6)}{.7498} - \underset{(-2.0)}{.29}\ S_{el} - \underset{(-4.2)}{.44}\ S_{cc} \\ R^2 = .8682 \end{array} \tag{3}$$

$$\begin{array}{l} e(1) = \underset{(9.5)}{.7115} - \underset{(-1.9)}{.28}\ S_{el} - \underset{(-4.0)}{.40}\ S_{cc} \\ R^2 = .8543 \end{array} \tag{3a}$$

Again the share of electric arc is not significant at the 0.95 level but what is important is that the coefficient for this process remains at the same level as for 1970, and continuous casting alone explains the main part of the variance:

$$\begin{array}{l} e = \underset{(8.6)}{.6473} - \underset{(-3.1)}{.40}\ S_{cc} \\ R^2 = .7001 \end{array} \tag{4}$$

$$\begin{array}{l} e(1) = \underset{(8.5)}{.6225} - \underset{(-2.9)}{.37}\ S_{cc} \\ R^2 = .6706 \end{array} \tag{4a}$$

Comparing fitted values for e(1), which eliminates the impact of the Martin process (see Table 10), it can be seen that the share of electric-arc steel contributes most significantly to the fit of the energy coefficient for Italy, where the share of this process still differs significantly from those in other countries (52.6% as opposed to 20-30% elsewhere).

Table 10. Actual and fitted values of the energy coefficient, 1982.

Country	Actual	Fitted Regression (3a)	Regression (4a)
Italy	.3199	.3423	.4067
UK	.5045	.4718	.4787
Japan	.3792	.3341	.3324
FRG	.4281	.4257	.3942
France	.3891	.4357	.4067
USA	.5468	.5294	.5301

Results of these analyses of cross-sectional data have been used to test whether intercountry differences in terms of the energy coefficients and the shares of different processes may be used in time-series analysis for a particular country. A complete set of data from 1970 to 1982 exists for Japan, while for the other countries some data are still missing, which makes time-series analyses rather weak. From the outset we have of course been aware that it is impossible to obtain significant, independent estimates of the impacts of the three variables used in the analyses because the share of both electric-arc steel and continuous casting have been increasing, while the share of the Martin process has declined sharply: these three variables are thus colinear*.

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[*] To demonstrate this point, we present the following regressions for Japan without further comment:

$$\begin{array}{llll} en = .5517 & + 1.5\ S_m & - .74\ S_{el} & + .02\ S_{cc} \\ (8.7) & (1.4) & (1.6) & (.2) \\ R^2 = .8329 \end{array}$$

Ignoring the effect of the Martin proces ($\hat{\beta} = .35$):

$$\begin{array}{lll} e(1) = .5456 & - .50\ S_{el} & - .06\ S_{cc} \\ (8.6) & (1.2) & (1.0) \\ R^2 = .7798 \end{array}$$

Thus the first steps in analyzing time-series data for a particular country are to construct a set of data in which the effects of the Martin, electric-arc, and continuous-casting processes are successively removed from the observed energy-coefficient values and then to estimate the possible impacts of the remaining factors on the dynamic behavior of the energy coefficient over time. The following notation and parameter values are used under the assumption that *a priori* bounds on coefficients are based on the results of cross-sectional analysis, which in general may correspond to upper limits on the time-series data:

$$e(m) = e - .24\ S_{martin}$$

$$e(el) = e + .3\ S_{el.\ arc}$$

$$e(cc) = e + .4\ S_{cc}$$

$$e(m,cc) = e - .24\ S_m + .1\ cc$$

$$e(m,el) = e - .24\ S_m + .3\ S_{el}$$

It is particularly important to trace back the time trend of an energy coefficient for a particular country after eliminating all (or part) of the above-mentioned effects.

We now consider case studies for three of the countries: Japan, the United States, and France.

Japan

The effect of the Martin process for Japan was negligible and the time trend remained essentially the same after this effect was removed. There was still a declining trend after removing the effect of the growth in the share of electric-arc steel. Figures 2, 3, and 4 show the plots of fitted and actual values of the regressions (1), (2), and (3), respectively. Regression (2) is done with the energy coefficient corrected by the effect of Martin steel. One can notice that there is nearly no difference between Figure 2 and Figure 3; the effect of Martin steel in the Japanese energy consumption is of little importance, considering the low share of this process in 1970. Figure 4 shows the plot of regression (3); the level of the corrected energy coefficient for this regression (effects of Martin and electric steel are removed) is well above the level of the two other coefficients considered, i.e. e, the non-corrected coefficient, and e(m) with no Martin effect. But there is still a declining trend over the period for this last regression.

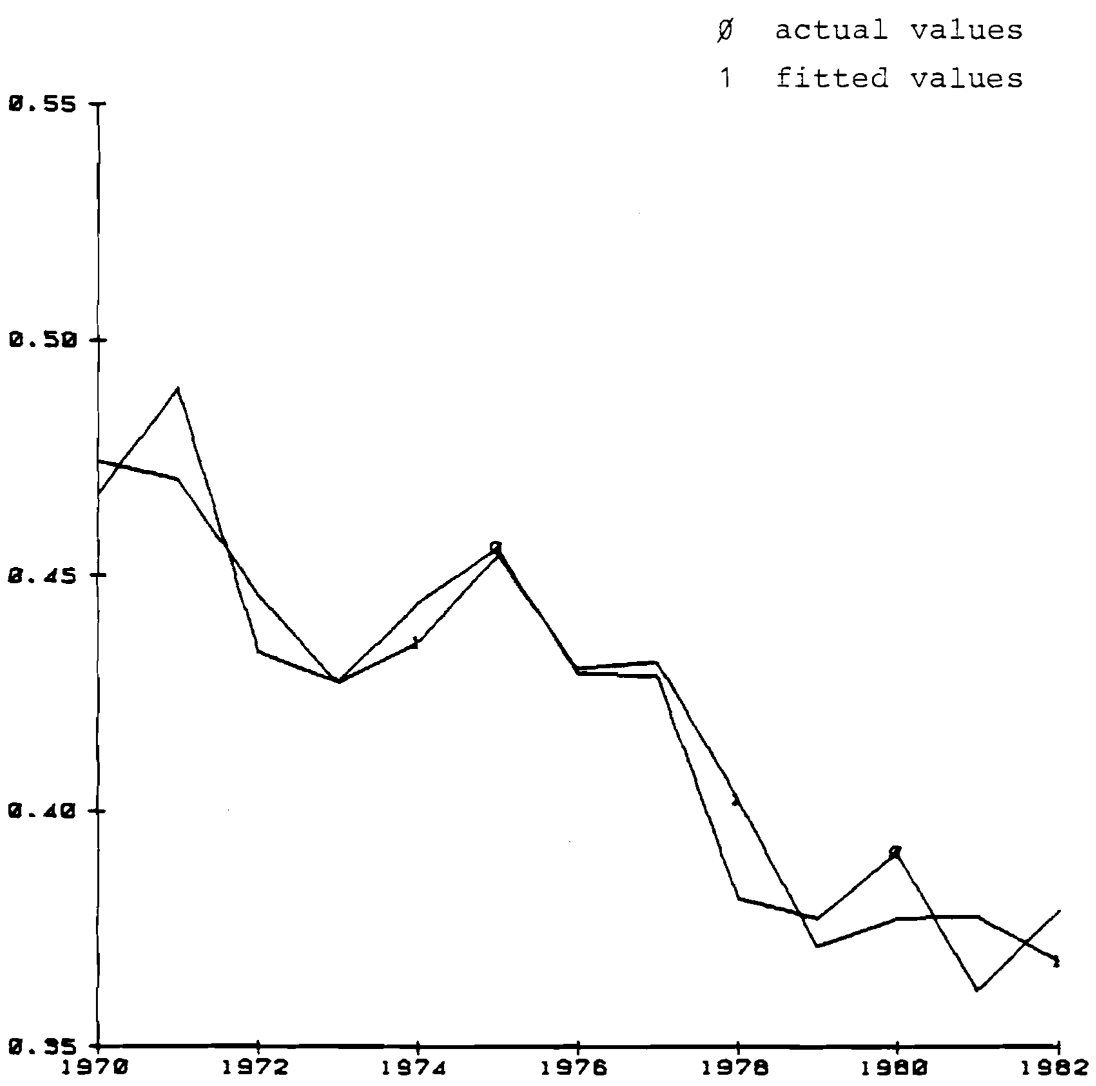

Figure 2. Actual and fitted values of regression (1) (Japan): regression of the energy coefficient.

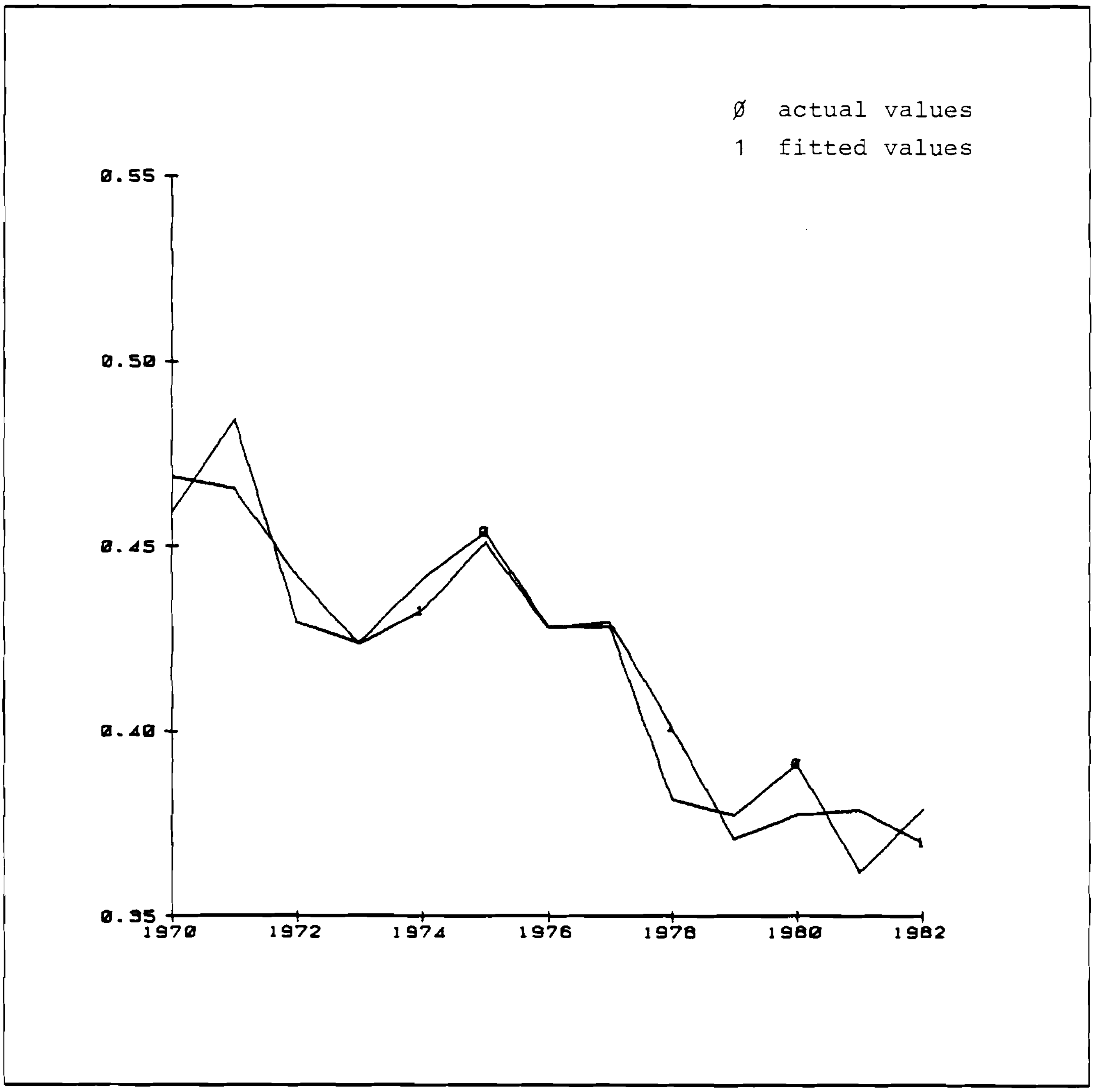

Figure 3. Actual and fitted values of regression (2)(Japan): regression of the energy coefficient corrected for the effect of the Martin process.

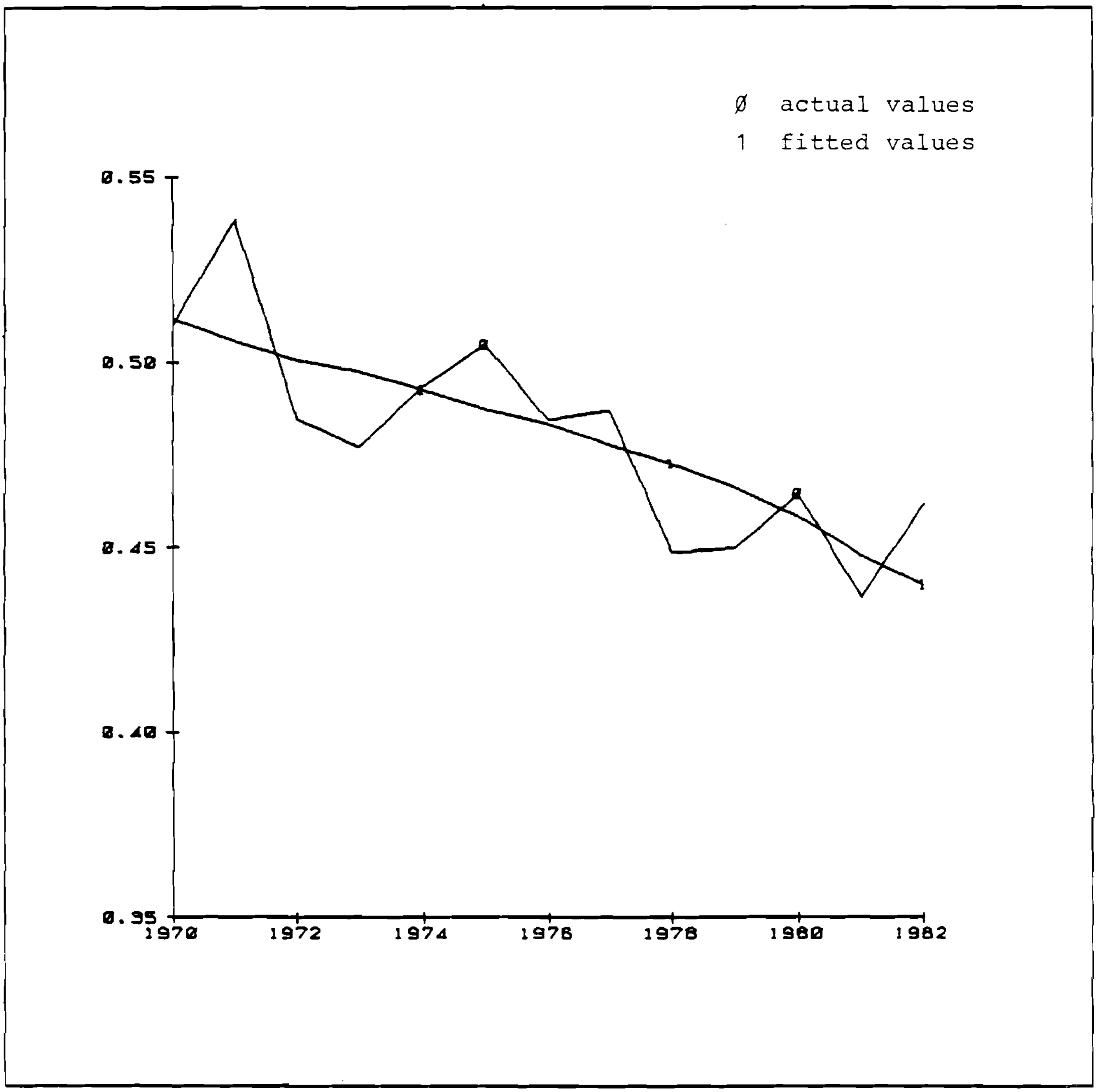

Figure 4. Actual and fitted values of regression (3)(Japan): regression of the energy coefficient corrected for the effects of the Martin and electric processes.

The three regressions are:

$$e = .5953 - .76\, S_{el} - .03\, S_{cc} \qquad (1)$$
$$\quad (18.8) \quad (-3.8) \quad (-0.9)$$
$$R^2 = .9082$$

$$e(m) = .5874 - .74\, S_{el} - .02\, S_{el} \qquad (2)$$
$$\quad (18.7) \quad (-3.7) \quad (-0.7)$$
$$R^2 = .8988$$

For the last variable (e(m,el)) we may estimate the impact of industry modernization through the share of continuous casting:

$$e(m,el) = .5184 - .094\, S_{cc} \qquad (3)$$
$$\quad (50.5) \quad (-4.3)$$
$$R^2 = .6233$$

This shows clearly that the cross-country regressions probably overestimated the impact of this factor (the estimated coefficient for continuous casting was .3). If this is indeed the case, then capacity utilization remains as an important factor. Since we had no detailed figures on capacity utilization, it was estimated as a variable "cap", which represents (as a percentage) the difference between the actual production in a given year and the average annual production during the period as a whole: for each year,

$$cap = 100(steel - 103.3)/103.3$$

where "steel" is the steel production during the year concerned. Then,

$$e(m,el,cc) = .5215 - .13\, cap$$
$$\quad (132.4) \quad (-2.7)$$
$$R^2 = .3952$$

Fluctuations of the energy coefficient over time are a function of capacity utilization, as can be seen for both peak and recession years. For example, if we take 1971 (a recession year), the actual figure differs by 14.4% from the average annual production during the period; this means an increase in the energy coefficient of .0187 compared to the situation in 1972, when production was approximately at the average for the period. The difference represents approximately 50% of the actual difference between energy coefficients in 1971 and 1972.

United States

The same procedure, when applied to the US case*, gives the following results:

$$\begin{aligned} e(m,el,cc) &= \underset{(51.98)}{.5928} - \underset{(-3.1)}{.22}\ cap \\ R^2 &= .6104 \end{aligned}$$

The coefficient for capacity utilization for the United States is nearly twice as big as that for Japan. The US steel industry has experienced many ups and downs in its production levels, and very severe crises, especially at the end of the 1970s and beginning of the 1980s: in 1979 production was 122.7 million tons, while by 1982 it had fallen to 67.14 million tons. Moreover, the US level of 'modernization' in the iron and steel industry has been somewhat lower than that of Japan, and one may assume that any changes in the level of production has had a direct impact on the measured 'energy efficiency'.

For the other factors, the results are as follows:

$$\begin{aligned} e(m,el) &= \underset{(12.7)}{.6180} - \underset{(-.9)}{.23}\ S_{cc} - \underset{(-2.4)}{.26}\ cap \\ R^2 &= .5839 \end{aligned}$$

(Different samples were used due to a lack of data on continuous casting for some years for the United States and France.)

France

Performing the same regressions for France gives the following results:

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[*] cap = 100(steel - 107)/107.

$$e(m,el) = .5638 - .17\ S_{cc}$$
$$(106.3)\quad(-10.3)$$
$$R^2 = .9467$$

$$e(m,cc) = .7516 - 2.16\ S_{el}$$
$$(40.2)\quad(-15.8)$$
$$R^2 = .9767$$

The capacity utilization factor is more difficult to introduce here: attempts to use the same procedure as for Japan and the United States produced nothing. It is possible to introduce capacity utilization as the difference between actual production and production capacity calculated as a polynomial function of time trend* in order to represent the evolution over time of the production capacity; this function expresses total capacity and the coefficient "cap" is now given by:

$$cap = 100(production - 23 - .57t + .063t^2)/$$
$$/(23 + .57t - 0.63t^2)$$

and regression on this coefficient gives:

$$e(m,cc,el) = .5659 - .13\ cap$$
$$(92.1)\quad(-1.5)$$
$$R^2 = .3482$$

for the period 1970-75. The coefficient of cap is insignificant at the .95 level of confidence, but its sign reflects the same trend as the two others. Conversely, for the period 1979-82 we get the following equation

$$e(m,cc,el) = .5268 + .31\ cap$$
$$(227.2)\quad(7.32)$$
$$R^2 = .9641$$

This results appears counterintuitive, but we must take into account the fact that some plants were closed, particularly

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[*] This polynomial function is calculated with a regression over the whole period.

in the last few years, and we may assume that the plants closed were the oldest and least energy-efficient. Anyway, the fall in production is correlated with the decrease in the energy coefficient over recent years; any more detailed explanation of this observation would require a somewhat deeper study of the industry.

Now we can compare net (or refined) energy coefficients across countries, i.e. the values of actual energy requirements less the effects of process changes and steel-production fluctuations:

Country	1970-71	1979-80
Japan	.51	.52
United States	.55	.55
France	.54	.54

One remarkable result is that Japanese steel production appears, on average, to be 8% more efficient than those of the other two countries, which, together with technological process achievements, makes its industry much more efficient.

The simple econometric approach presented here does have it weaknesses: for example, it is implied that energy savings within individual processes are unimportant if they are not associated with two major trends--a progressive decrease in the shares of inefficient processes and growth in the shares of continuous-cast and electric-arc steel. We can speculate as to whether energy savings will be greater in a country that restructures more slowly than in another, where the restructuring occurs more rapidly, but in-depth study would be necessary to validate or refute any such conclusions.

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