ARTICLES

*The Role of Energy Supplies during Western Europe's Golden Age, 1950-1972**

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I Introduction

In Western Europe's "golden age" of the 1950s and 1960s economic growth, according to virtually any definition, surpassed all historic records.[1] This paper hopes to contribute to an understanding of this achievement by exploring one theme which has been almost totally neglected in the economic historiography:[2] the role of energy, particularly in sustaining growth during the years of declining real energy prices between 1957 and 1972. Many statements were made, especially in the 1960s, claiming that a close relationship between cheap energy

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[1] A. MADDISON, *Phases of Capitalist Development*, Oxford University Press, 1982, p. 126.

[2] W.W. ROSTOW, *Why the Poor get richer and the Rich slow down: Essay in the Marshallian Long Period*, Macmillan, London, 1980 is isolated in being one study which does emphasise the influence of energy in the period's economic history. How shifts in the ratio of prices of primary and manufactured goods generate long waves in economic life provides the analytical framework. It is not an approach pursued in this paper. B. CHATEAU and B. LAPILLONE, *Energy Demand: Facts and Trends: A Comparative Analysis of Industrialized Countries*, Springer-Verlag, Vienna, 1982, also contains a great deal of valuable historical content and analysis.

and high growth existed.[3] Few were supported by serious analysis.

Since then the orthodoxy which has emerged is that, by contrast, the energy course pursued by Western Europe during the period under study was foolish and wasteful. It has been described as a "... situation in which European Governments and energy consumers allowed themselves to become ransomed in exchange for the benefits of a steadily falling real price of oil"; the energy crises of the 1970s are seen as the result.[4] This approach tends to analyse developments out of their historical context; it does not consider the feasibility of alternative energy strategies, either with reference to the one pursued at the time or in relation to any contemporary formulation or support for an alternative low-energy growth path.

Our approach to examining the implications of changing patterns of energy use from the mid 1950s to the early 1970s is rather different. By the 1960s many of the growth influences itemised by those seeking to explain the post-war boom were exhausting themselves (the backlog of technological opportunities, cheap and abundant labour supplies, the release of pent-up liquidity after the war). The question arises as to what additional factors may have helped to sustain growth in the later phases of the golden age. Energy supply trends did, we believe, contribute to West European economic growth in the 1960s. Falling petroleum prices permitted European importing nations to expand purchases of oil without undue burden on the balance of payments.[5] Our analysis, however, focuses on the role of energy in facilitating structural transformation. Crucial to the exceptional performance of the European economies were the achievements of the technologically advanced, high-productivity

[3] See OECD, *Oil: The Present Situation and Future Prospects*, Paris, 1973, p. 76.

[4] P.R. Odell, "The Energy Economy of Western Europe: a return to the use of indigenous resources", *Geography*, 290, 66, 1, January 1981, p. 2.

[5] J. Dunkerley, "The future of coal in Western Europe", *Resources Policy*, September 1979, p. 156.

sectors of manufacturing industry which, Cornwall has persuasively argued, acted as "engines of growth" in the West in this period. They were, he stated, "uninhibited in their growth and transformation processes by any serious or prolonged supply of labour constraint".[6] Here we develop a similar argument with respect to energy supply.

Firstly, the increased flexibility and competitiveness of energy markets from 1957 are summarised. Secondly, the energy-intensive nature of European industrialisation in this period is discussed. In the following section the limited problems which this caused are explained: fuel substitution involved switching to fuels which were not only cheaper, but which also (a) enabled savings in capital and labour to be achieved, and (b) delivered more "useful" energy for a given heat input, than was the case for the fuels which they replaced. Finally, the thesis is discussed that cheaper energy and fuel substitution created a favourable environment for technological innovation and investment in new processes.

II The Cheap Energy Period

A variety of well-known, mainly supply-side factors led energy markets to become increasingly competitive and flexible from the 1950s. These included: the world-wide exploration and development of low-cost oilfields, the expansion of oil-refining capacity in the consuming regions, improvements in oil-transportation technologies, as well as the entry of the multinational oil companies, with their aggressive marketing strategies, into the European energy markets.[7] Energy demand was boom-

[6] J. CORNWALL, *Modern Capitalism: Its Growth and Transformation*, Martin Robertson, Oxford, 1977, p. 96.

[7] Critical observations have been made on the pursuit of supply-side, cheap energy policies by West European governments in this period, and their toleration of actions by oil companies in undercutting coal. Fuel oil, in direct competition with coal, was priced at very low levels, while the prices of lighter products, not exchangeable

ing in the 1950s and 1960s. As Dunkerley says, the sharp increase in oil consumption was due more to the displacement of coal by oil in markets where they compete, rather than the rise of inherently oil-using sectors.[8]

The rapid substitution of oil for coal was favoured by a number of circumstances, but the most obvious were shifts in relative fuel prices. Table 1 presents one way of expressing relative price changes, and gives the ratios of indices of petroleum prices against an index of coal prices and against a consumer price index. The table reflects clearly the increasing competitiveness of oil against coal, and also underlines that the price of petroleum was falling substantially in real terms between 1956 and 1972, especially in France and Western Germany.

Partly as a result of petroleum's price competitiveness, its consumption increased about six-fold in Western Europe between 1955 and 1970, while that of coal declined. Though

Table 1

RATIOS BETWEEN ENERGY AND CONSUMER PRICE INDICES, FRANCE, WEST GERMANY AND THE UNITED KINGDOM ,1965-1972

	Petroleum over Coal			Petroleum over Consumer Prices		
	F	WG	UK	F	WG	UK
1956	100	100	100	100	100	100
1961	98.6	84.5	100.4	101.6	88.5	108.4
1966	89.7	67.3	93.5	80.3	68.1	74.7
1971	65.4	60.1	93.7	80.9	67.8	99.9
1972	64.2	55.4	88.3	76.7	62.6	95.7

Sources: UNECE, *Increased Energy Economy Efficiency in the ECE Region*, New York, 1976, pp. 30-34; DEPARTMENT OF ENERGY, *Digest of UK Energy Statistics*, various; A. MADDISON, *Phases of Capitalist Development*, Oxford University Press, 1982, pp. 240-1; EUROSTAT, "Elementary Series of Energy Prices, 1960-1982", Brussels, 1982.

with coal, were set at much higher levels. See R. PRODIS and A. CLO, "The Oil Crisis in Perspective", *Daedalus*, 10, 4, Fall 1975, pp. 91-95.

[8] DUNKERLEY, "The future of coal", p. 153.

national variations are masked, table 2 summarises the outcome of these fuel substitution trends in the region as a whole in the post-war era.

To the extent that some European countries were converting to oil, then they were realising the benefit of favourable price trends. National prices varied considerably, as table 3 giving our estimates of movements in real energy prices in four countries, shows.[9]

Obviously the overall average price of energy fell considerably more in economies which were switching to oil, and/or where governments deliberately pursued market-orientated,

Table 2

END-USE ENERGY CONSUMPTION BY ENERGY SOURCES: PERCENTAGE CONTRIBUTIONS TO TOTAL REQUIREMENTS

	1950	1955	1960	1965	1970	1972	1980
i) *OECD-Europe: Economy as a whole*							
Solid Fuels	81.8	72.7	58.7	43.2	29.6	23.7	23.2
Liquid Fuels	12.2	20.1	29.3	45.0	56.7	59.1	51.6
Natural Gas	0.3	0.8	1.7	2.2	6.2	9.5	14.3
Electricity	5.7	6.3	10.3	9.6	7.6	7.7	10.9
ii) *OECD-Europe: Manufacturing Industry*							
	1950	1955	1960	1965	1970	1972	1980
Solid Fuels	77.7	68.5	60.2	42.8	27.8	23.0	18.7
Liquid Fuels	10.2	16.0	23.6	38.1	49.7	49.3	42.2
Natural Gas	3.5	5.2	3.5	4.9	9.2	13.8	20.2
Electricity	8.5	10.3	12.6	14.2	13.2	13.9	18.8

Source: OECD, *Energy Statistics*, various.

[9] The Fisher index has the advantage of taking into account trends in the pattern of fuel substitution, without introducing too much bias arising from the weightings being distorted from consumers tending to prefer lower-priced items. The formula used was:

$$\sqrt{\frac{\Sigma PiQi}{\Sigma PoQi} \times \frac{\Sigma PixQo}{\Sigma PoxQo}}$$

Table 3
AVERAGE REAL ENERGY PRICES PAID
BY FINAL CONSUMERS

i) *Economy as a whole*

	West Germany	France	Italy	United Kingdom
1960	100	100	100	100
1970	71.2	72.7	56.7	93.8
1972	63.2	86.5	60.6	97.7
1980	234.4	155.5	83.0	81.4

ii) *Industry*

	West Germany	France	Italy	United Kingdom
1960	100	100	100	100
1970	84.5	70.5	56.6	70.5
1972	81.8	78.3	74.8	85.4
1980	199.6	148.8	92.2	93.8

Sources: EUROSTAT, "Elementary Series of Energy Prices, 1960-1982" Brussells, 1982; EUROSTAT, "Coal Prices, 1955-1970"; OECD, *Energy Statistics*, various; DEPARTMENT OF ENERGY, *Digest of UK Energy Statistics*, various; THE ASSOCIATED OCTEL CO LTD., "World-Wide Survey of Motor Gasoline Quality".

cheap energy policies, than in countries such as Britain: here it was believed that national interests were served by protecting the coal industry, and also — due to the fact that the country was the headquarters of two major international oil companies — by adopting policies which kept oil import prices well above those prevailing elsewhere in Europe. A combination of policy decisions and structural factors contrived to keep the United Kingdom still 46.5 per cent dependent on coal in 1970. In Italy by contrast, the oil-route and rapid industrialisation based on mounting imports of cheap petroleum led to the country using coal for only 9.8 per cent of its requirements in 1970, and relying 73.4 per cent on oil. The outcome of such developments was that in some countries, like Italy, average real energy prices fell considerably more between 1957 and 1972 than in Britain, which, one might say, barely experienced the cheap energy period.

III Energy-Intensive Industrialisation

Cornwall has shown that among OECD countries between 1957 and 1973 the average annual rate of growth of labour productivity was high in manufacturing industry relative to the ecnomy as a whole. The fastest growing economies, led by Japan and Italy, had the fastest growing industrial labour forces; in Western Europe the countries with the highest overall rate of GDP growth, led by Germany, Italy, France and the Netherlands, enjoyed the fastest rate of growth of industrial output and productivity.[10] Technological change and scale economies may have contributed to European growth, but simply because of the considerable differential in agricultural and industrial productivity, the structural shift of employment towards industry may be regarded as an important explanation of the regions's supergrowth in this period.

Having accepted the crucial role of manufacturing industry as an "engine of growth", our thesis may be elaborated that no constraint, arising from the scarcity or high price of fuel, on manufacturing growth was present in Western Europe over these years. This proposition's importance hinges on the fact that the particular pattern of industrialisation and modernisation embarked upon by the region's economies during the "golden age" was an energy-intensive one.

A brief digression on the nature of the historic relationship between energy consumption and economic growth may highlight the significance of this argument. Many studies have pointed to the wide diversity which exists in energy-economy relationships, even at comparable levels of per capita income. Some writers, however, have been able to discern evidence of a long-run tendency for energy consumption per unit of output to fall and converge in advanced economies over time.[11] These

[10] CORNWALL, *Modern Capitalism*, pp. 13-18.

[11] J. DARMSTADTER, P. TEITLEBAUM & J. POLACH, *Energy in the World Economy: A Statistical Review of Trends in Output, Trade and Consumption since 1925*, John

trends have been explained by postulating that the energy-content of economic activities changes as societies pass through phases of industrialisation; energy utilisation being low in agrarian societies and in early stages of development, increasing considerably as industrialisation proceeds, with the growth of smoke-stack industries, before eventually falling as the economy reaches higher levels of development with services and consumer goods industries assuming greater relative importance and improved technologies bringing increases in energy efficiency.[12] Dividing the percentage rate of growth in energy consumption by the percentage rate of growth in GDP produces a ratio which has been termed the output elasticity of energy coefficient. Because of volatile year-to-year shifts in its value, the energy coefficient is now discredited as a forecasting device among energy economists. However none have denied that it accurately describes long-term past relationships between energy consumption and output growth, and we employ it here in a less familiar role as a tool of historical explanation. If there is a tendency for the elasticity coefficient to fall towards, and below, unity, this would suggest that there is some basis for believing that long-term energy-economy relationships do follow the particular path, outlined above. Other writers, however, flatly deny finding evidence of the existence of any such trend.[13] A study of twenty-six European countries over the 1951-70 period led Smil and Kuz to state: "there is no general pattern of convergence to 1.0, or, for that matter to any other value".[14] It is probable, in our opinion, that this conclusion derived from the fact that Smil and Kuz's sample was restricted both in space and time, being

Hopkins University Press for Resources for the Future, Washington, DC., USA, 1972, pp. 70-72.

[12] Ibid, pp. 32-36; L.G. Brookes, "More on the Output Elasticity of Energy Consumption", *Journal of Industrial Economics*, 21, 1 November 1972, pp. 83-85.

[13] M. Slesser, *Energy in the Economy*, Macmillan, London 1978, p. 7.

[14] V. Smil and T. Kuz, "European Energy Elasticities", *Energy Policy* 4, 2, June 1976, p. 170.

concentrated indeed in a period which witnessed abnormal energy/economy trends in Europe.

Presumably a level of consumption will eventually be reached when it will become more difficult to "force" more energy into additional units of output. Noting the equality in national accounting terms between income and output, if there is a long-run tendency for the income elasticity of energy demand to fall below 1.0, then there are grounds for supposing that output elasticity will also in the long-run tend to move towards, and eventually below, unity. Though the studies investigating energy demand provide little uniformity of conclusion it does appear that the longer the time-span adopted the more plausible appears the hypothesis. Edmonson, for example, found that the long-run income elasticity of energy demand in the United States between 1901 and 1968 was 0.8.[15] Only one of a number of recently surveyed studies of energy demand in OECD countries extended the period investigated beyond 1973. This one makes it possible to contrast the 1960-73 OECD elasticity of 1.0, with a 1973-8 elasticity of 0.83, which finding is also consistent with the hypothesis.[16]

There are grounds for believing, therefore, that as economies move beyond the stage of early industrialisation their overall energy intensities will tend to fall. Table 4 gives our estimates, which convert and extend Darmstadter *et al's* calculations of energy coefficients in Europe and the United States from 1925 to 1965, up to 1980. Thereby a good impression of long-term behaviour is provided, which is certainly of energy consumption growing less rapidly relative to the growth of GDP in recent years compared to the earlier part of the period. However, critically, our additional figures underline that during the cheap

[15] N. Edmonson, "Real prices and consumption of mineral energy in the United States, 1901-1968", *Journal of Industrial Economics*, 23, 3, March 1975, p. 168.

[16] G. Kouris, "Energy demand elasticities in industrialized countries: a survey", *Energy Journal*, 4, 3, 1983, p. 77; N. Kouvaritokis, "Energy demand elasticities: a review of the literature", *European Economy* 16, July 1983, chap. 2.

Table 4
ENERGY-GDP ELASTICITY COEFFICIENTS*

	1925-65	1938-55	1950-65	1960-72	1972-80
USA	0.77	0.88	0.86	1.03	−0.02
OECD-Europe	—	—	0.82	0.94	0.56
Belgium	0.52	0.43	0.67	0.86	0.15
France	0.86	0.57	0.86	0.91	0.45
West Germany	—	—	0.71	0.91	0.35
Greece	—	—	1.46	1.44	2.26
Italy	1.86	1.90	1.93	1.94	0.79
The Netherlands	1.29	1.06	1.06	1.52	0.96
Spain	—	—	0.87	1.11	1.88
Sweden	1.40	1.15	1.60	1.13	−0.19
United Kingdom	0.57	0.94	0.54	0.33	−0.44

* See text for definition of output elasticity of energy consumption.
Source: J. Darmstadter, P. Teitlebaum and J. Polach, *Energy in the World Economy: A Statistical Review of Trends in Output, Trade and Consumption since 1925*, John Hopkins University Press for Resources for the Future, Baltimore, USA 1972; UN, *Yearbook of World Energy Statistics*, various; R. Summers and A. Heston "Improved International Comparisons of a Real Product and its Composition 1950-1980", *The Review of Income and Wealth*, 30, 2 June 1984.

energy phase of Western Europe's golden age, the secular tendency towards a less energy-intensive pattern of economic activity was temporarily reversed. Of the five sub-periods covered in the table it was clearly that of 1960-1972 which witnessed the highest rate of energy consumption relative to that of GDP.

The energy intensive pattern of industrial and economic growth is also borne out by data summarised in Table 5. This emphasises how rapidly energy consumption in manufacturing industry was growing in 1960-72 in Western Europe, invariably faster than in 1950-60 or 1972-80. Indeed a distinctive aspect of the 1960-72 sub-period is that in eight out of nine European countries the growth in manufacturing energy consumption was more rapid than the growth in manufacturing output. To conclude, whatever the causes, and rather against the long-run tendency in our view, the years from 1960 to 1972 were ones of

Table 5
GROWTH OF MANUFACTURING OUTPUT
AND MANUFACTURING ENERGY CONSUMPTION*

	1950-60		1960-72		1972-80	
	Manuf. output	Manuf. en. consump.	Manuf. output	Manuf. en. consump.	Manuf. output	Manuf. en. consump.
Belgium**	2.8	0.9	6.2	5.4	0.4	−0.7
France	4.8	4.4	3.2	4.7	2.2	1.1
Germany	9.1	5.7	3.4	4.2	1.5	−0.6
Greece	6.8	8.4	8.5	13.2	4.6	4.9
Italy**	6.2	10.1	7.2	8.1	4.2	−0.2
The Netherlands	7.7	5.6	3.3	10.4	0.9	0.6
Spain	—	5.3	7.7	9.2	3.6	3.2
Sweden	2.8	6.8	2.9	3.8	0.7	−0.7
United Kingdom	2.8	1.6	1.7	2.1	−0.7	−4.3
USA	3.0	4.0	2.9	3.9	1.4	−0.9

* Expressed as average annual rate of growth; manufacturing output in own currencies, 1980 prices; energy consumption in million tons of oil equivalent.
** First period is 1955-60.
Sources: OEEC/OECD, *National Accounts, Basic Statistics of Energy Balances*, various.

energy-intensive economic growth in Western Europe, particularly in the manufacturing sector.

IV Fuel Substitution and Energy Efficiency

The energy-intensive pattern of industrial growth did not arise because a reduction in the real cost of fuel encouraged energy use to become increasingly wasteful. The principal reason for rising energy-intensiveness, particularly in the manufacturing sector, was structural change.

A reasonable hypothesis is that heavier energy users will be most creative in seeking to reduce fuel bills, either through fuel substitution or technical improvements. In the late 1960s in Britain, France and Italy, after the energy transformation sector itself, cement was the most energy-intensive industry, with glass and ceramics, paper, iron-making and chemicals also relatively big energy users. Textiles, clothing and food were among the industries with a low energy intensity.[17] Energy productivity improved most, even in the period of falling energy prices in the 1960s, in energy-intensive industries. Pronounced falls in the ratio of energy inputs to the volume of output in the chemical industry, for example, occurred in all six European Community countries between 1960 and 1971. Energy productivity also improved in iron and steel and cement, but deteriorated in some countries in textiles, clothing and leather. A significant statistical correlation between energy-intensiveness and increases in energy productivity across Community industries, between 1947 and 1963, also provides support for the hypothesis.[18]

Despite appreciable gains in industrial energy productivity, the long-term tendency for energy intensity over industry as a whole to decline was muted, if not actually reversed, in Western Europe in this period. This was not because of the changing energy content of given industrial processes; it was primarily due to structural change. The rapidly expanding, advanced sectors of industry, Cornwall's engines of growth, were also invariably energy-intensive industries. The chemical industry, for instance, achieved easily the fastest rate of growth among main industrial groupings in OECD countries between 1955 and 1973.[19] Table 6 below also shows that for the European Community in the 1960s the fastest growing industrial sectors were mainly energy-intensive ones — chemicals, paper and steel — and the slowest growing industries included low energy users, such as food and textiles.

Community industrial energy consumption increased from 204.4 m.t.c.e. in 1960 to 319.0 m.t.c.e. in 1970; but the ratio of the output index to the energy consumption index (as a proxy

[17] Ranking by energy-intensity is made possible by input-output studies, see NEDO, *The Increased Cost of Energy: Implications for UK Industry*, H.M.S.O., London, 1974, pp. 69-70; UNECE, *Increased Energy Economy and Efficiency in the ECE Region*, United Nations, New York, 1976, pp. 17-18.

[18] Ibid, p. 14.

[19] CORNWALL, *Modern Capitalism*, p. 134.

Table 6
EUROPEAN COMMUNITY: INDUSTRIAL OUTPUT AND ENERGY CONSUMPTION, 1960-1970

	Energy Consumption (m.t.c.e.)*		Energy Consumption Index (1963=100)		Indust. Output Index (1963=100)	
	1960	1970	1960	1970	1960	1970
Industry (excl. energy sector)	204.4	319.0	91	142	85	153
Chemicals	38.9	71.5	86	158	75	201
Paper & Publishing	10.9	17.6	86	139	84	155
Machinery & Engineering	17.8	35.4	77	153	83	155
Steel	67.9	89.2	102	134	96	151
Non-ferrous metals	9.7	15.8	88	143	95	148
Non-metallic minerals	27.9	43.8	86	135	83	140
Food and Drink	14.0	20.9	90	134	87	133
Mining (exc. coal)	3.3	4.0	100	121	94	136
Textiles, leather, clothing	11.8	16.9	89	127	89	113

* m.t.c.e. = million tons of coal equivalent.
Source: EUROSTAT, *Energy Statistics Yearbook 1960-1971*, Brussels, January, 1972, pp. 2-4.

for overall industrial energy intensity) declined from 1.07 to 0.93 over these years. This barely perceptible alteration in the energy/output index ratio was itself clearly the product of significant movements with respect to firstly, structural shifts within industry as a whole, and secondly, changes in the specific energy consumption of individual industrial sectors. Unfortunately there insufficient are data to determine the relative importance of these two variables, but it does seem that the supergrowth of leading sectors like chemicals counterbalanced the tendency for overall energy-intensity to fall due to energy-saving technical progress and the decline of traditional smoke-stack industries.. This was certainly what happened in Western Germany in this period.[20]

[20] E. KRATZMULLER & K.D. FISCHER, "Structure of Industrial Energy Consumption in the Federal Republic of Germany - Present and Future Development" in The

Nowhere in Europe were the contemporary tendencies in the energy economy more strongly manifest than in Italy. Energy intensity in manufacturing and mining increased by some 30 per cent between 1953 and 1972, but the increase would have been much greater had it not been for energy-saving measures. The strongest component of change in industrial energy intensity was marked variations in the product mix. Although a number of low energy-intensive sectors, such as transport equipment, grew faster than manufacturing and mining as a whole, very energy-intensive sectors like chemicals, steel and paper also grew equally rapidly, chemicals and steel, indeed, clearly dominating the energy picture.[21]

There was a conscious intent in Italy in this period to encourage a pattern of industrialisation which exploited the country's relative geographic proximity to the oil-producing regions, so as to promote an energy-intensive economic transformation and modernisation of industry based on cheap imported oil.[22] The changing structure of energy consumption made possible, in such cases, a shift of the centre of economic activity away from the coalfields and heat-intensive industries of North Western Europe. As in the Marseilles area, regional industrial take-offs occurred, involving the development of oil-refining and petrochemical complexes, and based to some degree on new-found locational advantages with respect to access to imported oil, or local sources of natural gas or hydro-power.[23]

Eighth *World Energy Conference* (hereafter *WEC*) Proceedings, Bucharest, Romania, June-July, 1971, Paper 1.1-99, pp. 7-14.

[21] O. Bernardini, "Structure and Technology as Determinants of Energy Demand in Post-World War II Italy", in IEA, *Workshops on Energy Supply and Demand*, OECD, Paris, 1978, pp. 345-9. While total industrial output in Italy grew by 86.0 per cent between 1960 and 1971 and industrial energy consumption by 97.4 per cent, chemical output, for instance, grew by 181.5 per cent and chemical energy consumption by 140.8 per cent. Estimated from Eurostat, *Energy Statistics Yearbook 1960-1971*, Brussels, January 1972, pp. 11-13.

[22] C. Ferroni, "Le rôle de l'énergie dans l'industrialisation en Italie", in Eighth *WEC* Proceedings, paper 5.1-162, pp. 2-6.

[23] "Marseilles à l'heure de Fos. Le dossier d'une industrialisation", supplement au *Enterprise*, 748, 10 January 1970, pp. 3-9.

Industrialization during Western Europe's golden age was above all an energy-intensive process; and this was primarily because the very rapidly expanding leading sectors of manufacturing were also energy-intensive industries. This path of energy-intensive growth, however, proved to be a less difficult or costly development than it might have been because the concurrent process of fuel substitution had two significant effects. Firstly, the fuels preferred were those most rapidly falling in price, so there was a substantial reduction in the cost of purchasing a given amount of energy. Secondly, the fuels preferred had higher end-use efficiencies; consequently there was an increase in the amount of "useful" energy available to consumers from a given amount of heat supplied.

The decline in average energy prices has been noted, but at a more disaggregated level there were considerable variations experienced for industrial consumers in different countries. For example, industrial fuel oil prices in real terms fell by about one-half between 1960 and 1970 in France, the Netherlands and Italy, with more modest reductions in Western Germany and the United Kingdom. Reductions in electricity prices paid by industrial consumers in these five countries were not spectacular in the 1960s except in Italy (a drop of about 70 per cent), while there were considerable variations in the decline in the real price of natural gas paid by industrial customers (for example, almost halving in Western Germany, but virtually stable in the United Kingdom).[24]

To the degree that countries were converting to oil and natural gas, and to the extent allowed by government pricing policies, then the cost of supplying a given amount of energy fell considerably relative to the price of other inputs. Over the period 1956-1972, petroleum prices fell to 44.4 per cent of their initial level, relative to the price of labour as expressed in wages,

[24] Calculated from data supplied by Eurostat, "Elementary Series of Energy Prices, 1960-1982", Brussels, 1982.

in France, and to 25.6 per cent in Western Germany. In comparison to the cost of investment goods as expressed in building costs and the price of machinery, petroleum prices fell to 77.4 per cent of the 1956 level over this period in France, and to 41.2 per cent in Western Germany.[25] Thus at a time when the prices of other factors of production, such as labour, were rising significantly, other things being equal the fall in energy costs effectively released resources for enterprises to devote to other purposes.

Price competitiveness was undoubtedly a crucial factor in determining the choice of energy products in many applications, but it was not the only reason for converting to oil or natural gas. The ease and cost of handling and storing fuels, the investment costs of conversion, and receptivity to process control were other factors influencing consumer choice. In such respects oil and natural gas presented many advantages over traditional fuels. Oil combines the dual attraction of possessing less volume than a ton of coal, while yielding more energy. Thus the ton-mile in moving energy in the form of oil is less, and over nine times as much groundspace is required for storing in the case of coal the heat equivalent of 10,500 tons of oil. Oil is conveniently handled, is less lieable to damage in transit than coal, and also burns more cleanly and in a more controlled fashion than solid fuel. Receptivity to process control meant, therefore, that considerable reductions in the time cycle of production for many purposes were possible by converting from coal to oil. Natural gas is an even more superior energy source: readily controlled and creating fewer pollution problems, it reduces capital costs through savings on storage, construction costs and — through its purity — the longer life of plant.

The capital- and labour-saving attractions of converting to oil or natural gas were, therefore considerable. This accounts in

[25] UNECE, *Increased Energy Economy and Efficiency in the ECE Region*, New York, 1976, pp. 33-4.

part for these fuels' increased penetration into West European energy markets in this period. While the labour-saving aspects of fuel substitution are often noted, virtually all contemporary studies of industrial energy use restrict their quantification of the benefits effected by fuel conversion to energy savings alone. We are consequently forced to a rather impressionistic survey of the evidence relating to the other resources saved through fuel substitution. Bending's analysis of the British industrial fuel market between 1953 and 1970 led him to observe that new oil- or gas-fired plant was generally cheaper than equivalent coal-fired plant; substitution away from coal had a variety of practical and economic benefits — release of space for coal storage and handling, the reduction of the environmental impact, the reduction in labour requirements and improvements in working conditions. Conversion to oil or natural gas also often involved a change in production technology, which brought about a simplification of the production system and savings of all factor inputs.[26] This above all derived from the displacement of indirect by direct processes, as for example in the British pottery industry in the 1950s and 1960s. In the latter combustion occurs in the same chamber in which products are fired; in the former it takes place in a separate chamber. Evidence relating to the transfer to oil- and gas-firing in industrial boiler plant, and from the glass industry, testifies to the reduced running costs and manpower requirements resulting from the conversion to the new fuels; the way in which the fuel transfers facilited the adoption of improved techniques involving automation also emerges in a number of cases.[27] Thus the penetration of oil and gas into

[26] R. Bending, "Industrial Fuel Use - Mechanisms of Change", Energy Discussion Paper, Energy Research Group, University of Cambridge, December 1980, pp. 6-7.

[27] P.K. Cattell, "Structuring Industrial Energy Usage", Energy Discussion Paper, Energy Research Group, University of Cambridge, October 1980, p. 106; Energy Technology Division, Dept. of Energy, "Energy in the United Kingdom 1967-1972", in ninth *WEC* Proceedings, Detroit, 23-7 September 1974, Paper 1.2-32, p. 696.

the French cement industry in the 1950s and 1960s permitted the automation of furnaces and the removal of machinery which had been necessary for the crushing and drying of the displaced fuel, coal.[28]

The qualities of the newly introduced fuels allowed significant improvements to be achieved in the intensity of plant use. Conversion from coal to oil in the 1950s led to considerable increases in the weekly output of plant in a variety of British industries; this was particularly due to the controlability, flexibility and high combustion temperature of oil. In the chemical industry vitriol production at eight stills was quoted at increasing from 1680 to 1900 tons per week, after conversion to oil, with manpower requirements falling from 400 man hours/week to 120 man hours/week. In brick-making the introduction of oil-using "Belgian" kilns enabled a 40 per cent increase in weekly production to be achieved, with the firing cycle being reduced from 21 to 16 days.[29] The way natural gas cut into the Italian industrial fuel market in the 1950s and 1960s was especially noticeable, particularly in the energy-intensive sectors of metallurgy, glass and ceramics, where the qualities of the final product were influenced by the type of fuel used. In such cases the high purity characteristics, the high combustion temperature and the ease of regulation were exploited to the full.[30] The introduction of natural gas in Siemens-Martin steel plants, enabled the automation of processes and the finer control of temperatures to be effected, in turn enabling considerable reductions in manpower requirements at each stage of manufacture to be achieved. In the Italian cement industry, conversion to larger oil — or gas — us-

[28] R. Caraffa, "Les Besoins en énergie du secteur 'industrie' ", *Revue française de l'énergie*, 182, July-August 1966, p. 565.

[29] T.C. Bailey & R.J. Bressey, "The Use of Oil as a Means to Greater Productivity", in Transactions of the *World Power Conference (WPC)*, Montreal, 7-11 September 1958, vol. 6, paper 29 G/4, pp. 2530-4.

[30] G.M. Sfligiotti & I. Maruzzo, "Natural Gas in Italian Energy Economics", in Ninth *WEC* Proceedings, op. cit., paper 1.2-11, pp. 287-97.

ing equipment was associated with the installation of rotary kilns, which in turn made labour economies possible with respect to the receiving, storing, grinding and transportation of fuel, the feeding of furnaces, the regulation of combustion, the treatment of clinker, and, as in other industries, such as metallurgy, where newer fuels were replacing coal, it led to the elimination of ashes and therefore the avoidance of a labour-intensive stage at the end of the production cycle.[31] Such changes often led to reduced running expenses and labour costs. The modern large-scale kilns, for example, with more sophisticated instrumentation, could be manned by workers with little skills and training compared to that required for operating traditional equipment. In Japan, where there were major developments regarding the modernization of the industry and conversion from coal to oil, cement output increased 230 per cent between 1953 and 1962, and labour productivity improved threefold.[32]

Some of the characteristics of particular fuels can be compared and expressed through the concepts of "useful energy" and fuel efficiencies. The end-use efficiency of individual fuels depends on the technology in which the fuel is applied and the performance characteristics of the engines used. Extensive information and knowledge is required to estimate fuel efficiencies, which express the proportion of useful energy made available as a proportion of the heat supplied. It was estimated that in industrial uses gas had an efficiency of some 85 per cent, against only 70 per cent for coal; in transport oil's estimated efficiency was 22 per cent, but coal's was only 4.4 per cent. While since 1974 there have been considerable improvements in coal-firing techniques, which have brought a significant increase

[31] C. Padovani, "L'Industrie du Gaz Naturel en Italie", in Transactions of Sixth *WPC*, Melbourne, 20-7 October, 1962, paper 146, II, 3/7 pp. 1060-1.

[32] K. Saji, "On the Effective Utilization of Energy in the Japanese Cement Industry", in Transactions of *WPC*, Lausanne, 13-17 September 1964, vol. 4, A-4, paper 73, pp. 2582-92.

in end-use efficiency in industrial applications, in the 1950s and 1960s these techniques were not available hence the discrepancies in fuel efficiencies. Converting away from coal to oil, natural gas or electricity meant more useful energy was being employed from a given input of heat. The advantages were dramatically exploited in the electrification or dieselization of European railways in the period.[33] The switch from steam to diesel on the UK railways, for example, was largely responsible for the reduction by a factor of five of the net energy requirements of the sector between 1960 and 1972.[34]

When account is taken of the prevalent fuel substitution trend,the energy intensiveness of West European industrialization in the cheap energy period emerges even more strongly. Conversion to more efficient fuels meant that more energy was being made available and consumed than unadjusted figures, expressed in calorific equivalents, would suggest. Adams and Miovic found that the pooled, unadjusted elasticity coefficient for OECD countries in the 1950-62 period was 0.816 for industrial production, and 0.910 for GDP as a whole; after taking into account the fuel efficiency factor, however, they found that the "useful" energy elasticity coefficient had increased to 1.1 for industry and to 1.35 for GDP.[35]

We have also recalculated our elasticity coefficients to take account of the changing structure of energy consumption and differing fuel efficiencies, which are shown below, table 7.

The figures show that between 1960 and 1972 in four out of

[33] Fuel substitution in the European Community permitted total railway energy consumption to decline by 29 per cent between 1950 and 1960, while traffic grew by 20 per cent and the quantity of energy used per ton-kilometre fell by 40 per cent. V Paretti and G. Bloch, *Energie et Expansion Economique: Evolution 1950-1961 et previsions pour 1965 et 1970 dans la Communauté Européene*, Ginffrè for ENI, Milan, 1963, pp. 121-2.

[34] W.S. Humphrey & J. Stanislaw, "Economic Growth and Energy Consumption in the UK, 1700 - 1975", *Energy Policy*, 7, 1, March, 1979, p. 41.

[35] F.G. Adams & P. Miovic, "On Relative Fuel Efficiencies and the Output Elasticity of Energy Consumption in Western Europe", *Journal of Industrial Economics*, 17, 1, november, 1968, p. 54.

Table 7

ENERGY-GDP USEFUL ELASTICITY COEFFICIENTS*

(unadjusted coefficients in brackets)

	1950-65	1960-72	1972-80
France	1.13 (0.86)	1.33 (0.91)	0.52 (0.45)
West Germany	0.92 (0.71)	1.52 (0.91)	0.15 (0.35)
Italy**	1.48 (1.93)	1.24 (1.94)	0.33 (0.79)
The Netherlands	1.22 (1.06)	2.52 (1.52)	0.42 (0.96)
United Kingdom	0.64 (0.54)	0.89 (0.33)	−0.45 (−0.44)

* Useful energy efficiencies taken from W.D. Nordhaus, "The Demand for Energy: an International Perspective", in Nordhaus ed., *Proceedings of the Workshop on Energy Demand*, International Institute for Applied Systems Analysis, Luxemburg, Austria, 1975, p. 527.
** First period 1955-65.
Sources: As for table 4.

the five West European countries the consumption of useful energy was growing even more rapidly, relative to the growth of GDP, and also compared to the earlier and later sub-periods, than our previous, unadjusted figures had indicated. The one anomaly is the Italian case, where the decline in the adjusted coefficient can be partly attributed to a considerable drop in the relative importance of electricity (with a very high end-use efficiency) in Italian energy balances, from 26 per cent in 1960 to under 9 per cent in 1972. In general, though, the exceptionally marked energy intensiveness of West European economic growth in this period is confirmed by the figures. What also emerges strongly from this section is the clear good sense of European energy consumers over the period studied in converting vigorously to energy products which were cheaper, more versatile, and more efficient than those which had previously dominated the regions's energy scene.

V Fuel Substituion and Technological Innovation

Energy used in production processes accounts for well over eighty per cent of the energy consumed in industry (heating, lighting and other general purposes making-up the remainder). Of this eighty per cent about fifteen per cent is devoted to mechanical, usually specifically, electricity uses.[36] We are therefore concerned primarily with fuel substitution possibilities for process heat applied in industrial applications, which in fact, accounts for most of the energy consumed in industry. Romig and O'Sullivan have alluded to some of the ways in which conversion from coal to oil contributed to growth and an improvement in living standards in this period, but virtually all their points relate to developments in transportation and space heating. They mention that "more efficient industrial processes" were achieved through interfuel substitution, but do not elaborate any further on the argument.[37] Adopting a broad perspective Berg emphasized that the switch from wood to coal offered not merely enhanced heating value to run industrial equipment. 'It offered the opportunity to develop new and more productive processes', which indeed established the technological foundations of the modern steel and chemical industries during the third quarter of the nineteenth century.[38]

Schurr extended the analysis to a later stage of fuel substitution, examining the United States, in the period 1880 to 1980, which led him to propose a number of hypotheses regarding the sources of productivity growth. Essentially he believed that low-cost, abundance and enhanced flexibility in energy use provided a rich soil for the discovery and diffusion of new processes; this led to improvements in overall productive efficiency greater than what would have been expected from the increased inputs of energy. Imaginative technological developments in the utilization of energy led not only to improvements in energy

[36] Château and Lapillone, *Energy Demand* pp. 138-9.

[37] F. Romig & P.O'Sullivan, "Interfuel Substitution in European Countries", in P. Tempest ed., *International Energy Options: An Agenda for the 1980s*, Graham & Trotman, London for I.A.E.E., 1981, p. 133.

[38] C.A. Berg, "Process Innovation and Changes in Industrial Energy Use", *Science*, 199, 4329, 10 February 1978, p. 609.

productivity, but to increases in labour and capital productivity as well. Electrical and liquid fuels, for example, offered enhanced productive flexibility and supported the evolution of technical change.[39]

Schurr explores these hypotheses only in the most summary form with respect to US manufacturing between 1880 and 1980. His brief discussion leads one to consider how flexible and competitive energy market conditions, obtaining in Western Europe between 1957 and 1972, may have stimulated the development of technologies which would realize the cost advantages of conversion to cheaper, alternative fuels. The rapid overall growth and the increases in energy productivity in the energy-intensive branches of European industry in this period have been noted. However on the face of it, it is hard to see why cheaper energy should stimulate technological development, other than energy-intensive technical change.

Crucial factors are the characteristics of the production function in industry, including the degree of substitutability or complementarity between the factors of production, capital, labour and energy.

Research into the derived demand for energy and non-energy inputs has not, however, provided unambiguous findings; among other things the results are strongly influenced by the assumptions adopted and the quality of data employed. The general impression is that in the short-run, energy and labour are only slightly substitutable, while energy and capital display substantial complementarity.[40] A study of electricity use in UK industry, for example, showed demand for this fuel to be highly responsive to changes in output and fuel technology, but re-

[39] S.H. Schurr, "Energy Use, Technological Change and Productive Efficiency in the United States: An Economic - Historical Interpretation", in *Energie in der Geschichte*, Eleventh Symposium of the International Cooperation in History of Technology Committee, Düsseldorf, 1984, pp. 300-1.

[40] E.R. Berndt & D.O. Wood, "Technology, Prices and the Derived Demand for Energy", *The Review of Economics and Statistics*, 57, 3, August 1975 pp. 259-267.

latively unresponsive to price.[41] Such results hardly indicate how falling energy prices might stimulate technological innovation.

On the other hand when attention moves from the short- to the long-run a different picture emerges. Griffin and Gregory examined the derived demand for inputs from pooled data derived from nine West European countries and the United States over the period 1955-1969. A limited scope for substitution between energy and non-energy inputs is confirmed by this study for the short-run; but for the long-run the authors find that capital and energy are substitutes, not complements, and that demand for the factors of production, including energy, is significantly influenced by relative prices.[42] Lynk in a study of UK energy demand, 1948-1981, observed that long-run own price elasticities of demand for fuel are greater than the short-run equivalents, and in the case of petroleum and gas his results suggested there is considerable elasticity of demand once sufficient time has elapsed for capital to be changed. He offered the further insight that in the short-run, substitution of energy by non-energy inputs takes the form of a variety of conservation measures (such as more effective use of thermostat controls), but in the long-run such substitution will affect not only the *level* of energy resource use, but also the type of resource and their associated technology.[43] It appears that in this period of falling real energy prices in Western Europe, enterprises — though restricted in what they could do in the short-term — in the long-term were endeavouring to pursue an economically rational growth path, and were substituting relatively cheap energy for relatively expensive non-energy inputs, including capital.

[41] R.E. Baxter & R. Rees, "Analysis of the Industrial Demand for Electricity", *The Economic Journal*, 78, June, 1968 pp. 277-96.

[42] J.M. Griffin & P.R. Gregory, "An Intercountry translog model of energy substitution responses", *American Economic Review* 66, 5, December 1976, pp. 845-56.

[43] E.L. Lynk, "The Demand for Energy by UK Manufacturing Industry", Oxford Institute for Energy Studies, EE1, 1985, p. 16.

By the early 1950s a backlog of technological opportunity had accumulated over the previous twenty years of war and depression. It might be hypothesized that decisions to adopt labour-saving technologies in this era were encouraged by the knowledge that the resultant increased energy requirements could be quite easily borne, insofar as the acquisition of new capital equipment was tied in with conversion to cheaper, more efficient fuels. According to a study by Echiburu technical change was the main factor propelling productivity growth in UK industry in 1948-1975, but the increase in labour productivity was also achieved by substituting energy for labour. A German study also confirmed the considerable extent of substitution possibilities between energy and labour in manufacturing between 1963 and 1972.[44] Echiburu, moreover, found in this period, 1963-1972, in Western Germany, Sweden and Japan, and to a lesser extent in Britain, energy-intensive, labour-saving technical progress in industry was achieved at very little cost in terms of extra energy requirements; even in Britain, where the potential for substituting mechanical energy for human energy was less fully realized than elsewhere, the marginal energy requirement of one man-hour (1948-1975) was extremely small.[45]

Although the discussion hitherto has indicated the strong possibility that labour-saving, energy-intensive technical change did occur in Western Europe during the cheap energy period, entrepreneurs may simply have been adopting least-cost factor combinations.[46] This conclusion, furthermore, rather conflicts

[44] R. Linde & H. Moller, "Substitionsbeziehungen Zwischen arbetskraft und energie in der Westdeutschen Industrie, 1963-72", *Kyklos*, 32, 3 1979, pp. 587-602.

[45] On average it was estimated to be only 2kwh per man-hour. M.R. Echiburu, "Energy Analysis of Energy and Labour Substitution in Manufacturing", unpublished MSc thesis, University of Strathclyde, 1977, p. 66.

[46] This could be simplistically represented on a production function diagram by a pivot of the iso-cost curve, as producers use more energy at no extra cost to take advantage of relative prive changes, rather than the more fundamental shift of the iso-quent towards the axis, which arises from neutral technological innovation permitting less of all inputs being required to produce a given output.

with that of the previous section, which was that energy intensity did increase, but at an aggregate level due to structural change; at a sectoral level energy productivity growth and energy-saving measures were identified. We have not, therefore, moved much closer to understanding how the changing energy market situation of the period may have stimulated imaginative innovations in Europe in line with Schurr's hypotheses.

Dunkerley has stated that very little is known about the complex linkages operating in this area. She believed that what occurred in the industry sector of OECD countries between 1960 and 1970 was that some substitution of capital equipment and energy was made for labour, in response to rising labour costs, but that this was more than offset by technological developments; that is, on account of the introduction of more energy-efficient equipment, energy intensities, as in Swedish (and much European Community) industry in this period, could still fall.[47] The fact that much capital equipment in Europe in the 1950s was very outdated meant that the basic renewals of plant would almost inevitably produce significant improvements in energy productivity, as well as representing in some cases technological advances. There was much pre-war industrial plant in existence in Italy in the 1950s, and in the chemical industry its replacement may have contributed to a 10 per cent reduction in energy intensity in 1953-1960.[48] Between 1953 and 1970 industrial output grew by over three per cent per annum in the United Kingdom. As Bending says this growth in production created opportunities for the replacement of old, inefficient plant by modern, efficient plant, using the most economical fuels.[49]

Renovation of capital stock was thus a vital factor in achieving improvements in factor productivity. The Belgian brick-

[47] J. Dunkerley, *Trends in Energy Use in Industrial Societies; An Overview*, John Hopkins University Press for Resources for the Future, Washington D.C., USA, 1980, pp. 97-100.

[48] Bernardini, "Structure and Technology in Post-World War II Italy" p. 348.

[49] Bending, "Industrial Fuel Use", pp. 6-7.

making and British cement industries, for example, experienced a slow development of output in this period. This was linked with a limited renovation of plant and muted gains in labour and energy productivity. By contrast the German cement industry, whose output increased by 170 per cent between 1950 and 1962, became one of the most efficient in the world by the end of the period, consisting largely of modern plant with very little capacity dating before 1955. Productivity gains were not simply due to refinements in technique, but were the outcome of technological innovation — with the dry process of cement-making increasing its share of output from 11 per cent in 1950 to 54 per cent in 1962. The French cement industry underwent a similar technological transformation ten years later, and was beginning to approach German efficiency levels by the 1970s.[50] Though motivated by overall productivity gains rather than energy efficiency as such, across a number of European energy-intensive industries energy productivity often improved substantially with the replacement of obsolescent plant by new technology.

For Schurr's hypotheses to be convincing in the West European context in this period we would expect to find instances of investment decisions being made, embodying a significant technological advance, which advance however, also took advantage of and required conversion to a more efficient energy source. In this situation the increasingly flexible, competitive state of energy markets could be regarded as contributing to imaginative technological innovations. Only detailed case-studies will shed light on how widespread such innovations were, but there appear to be a number of cases where Schurr-type innovations did occur, for instance, in the steel, chemicals, glass and ceramics industries.

Not all instances of interfuel substitution, which did yield significant improvements in efficiency, however, necessarily in-

[50] J.P. Abraham, K.H. Bloemer and K. Tavernier, "Progrès technique, croissance économique et consommation d'énergie", *Revue d'Economie Politique*, vol. T, 75, 1964, pp. 361-81; Château and Lapillone, *Energy Demand*, pp. 175-8.

volved a major replacement of equipment or change in technology. For example, the injection of fuel-oil or natural gas, with oxygen, superheated air, or in other combinations in steel furnaces in France, Luxembourg and Belgium from the 1950s, and later in Britain involved only a modest adaption to existing equipment, with relatively small additional investment. This modification, nevertheless, enabled significant increases in labour and energy productivity to be secured.[51] *After* the pottery industry had made the transition to direct-firing, pottery kilns allowed fuels to be interchanged very readily, thereby enabling the industry to take advantage of changes in price and availability; thus in Britain the industry converted on a major scale from town to natural gas, and to a lesser extent to liquified petroleum, without any basic change in equipment, in the years 1969-1972.

Interfuel substitution, could, therefore, occur quite independently of important technical changes. In terms of significant, long-term progress in industrial energy technology, however, what does seem to have been important was not so much the substitution of one energy source for another, as the replacement of indirect processes of production, frequently dependent on non-premium fuels, by direct processes of production, invariably dependent on premium fuels. As Bending observed the move in many industrial sectors in this period from the use of solid fuels, fuel oils or heavier petroleum products to natural gas, electricity and lighter petroleum products was an example of technological replacement, which led to efficiency improvements.[52] As we have seen converting to natural gas led to significant improvements being made with respect to the automation of processes, process control, and requirements of space and manpower. There were a number of specific attempts by engineers to develop new equipment for use in metallurgical plant in France in the 1960s so as to permit the use of natural

[51] R. LAURIENT, "Les Nouvelles Applications des Produits Petroliers en Sidergie", in Transactions of Sixth *WPC*, op. cit., paper 172, IV, 1/4, ppp. 3535-3568.

[52] BENDING, "Industrial Fuel Use", p. 2.

gas and to exploit its special characteristics.[53] These cases would seem to come close to bearing out Schurr's hypotheses where fuel conversion was tied up with a significant technological advance.

These themes could well be illustrated by case-studies of the ceramics and glass sectors in the post-war period. These industries are especially interesting in being high energy-intensive industries (fourth out of 45 sectors in the Italian input-output tables for 1965, sixteenth out of 90 sectors for the British tables for 1968), which experienced a series of shifts in the structure of fuel consumption in the post-war period. From being heavily dependent on coal, they switched over to petroleum-based products in the 1950s and 1960s, only for natural gas to make major inroads into the British market in the 1970s — earlier in Italy; while North Sea natural gas did not reach potters in Stoke-on-Trent until 1969, the fuel was already widely used in Italian industry much earlier. Finally after 1979 electricity advanced its share. The switch away from coal to oil- or gas-firing, as in the Italian and British ceramics industries from the 1960s, was the major break-through. Up to 1957 coal had been the dominant fuel used in the British industry, yet it was only employed in obsolescent plant. In coal-fired kilns, the ware had to be protected from ash and sulphur oxides, and placed in a container separate from that in which combustion took place. The advent of direct-fired kilns, employing premium fuels, achieved a much higher degree of process control and reduced the requirements of skilled manpower; product quality also benefitted from the substitution.[54] In the 1970s technological change permitted the potentially most desirable and convenient fuel of all to the glass-makers, electricity, to be employed. Two problems hitherto

[53] "Le 82e congres du Gaz", *Revue francaise de l'énergie*, 173, September 1965, p. 495.

[54] PADOVANI, "L'Industrie du Gas Naturel en Italie", p. 1061; W.H. HOLMES & E. DAVIES, *The Pottery Industry: Energy Conservation and Utilization in the Pottery Industry*, Energy Audit Series, No. 7, A Report prepared for the Dept. of Industry, August, 1979, pp. 12-15.

associated with the use of electricity in glass-making — high refractory wear and tear and power dissipation — could be overcome. From 1979 glass-makers began to convert to electricity for certain processes, which achieved higher energy savings, improved product quality and lower rejection rates.[55]

VI Conclusion

In this paper we have adopted Cornwall's view that central to any explanation of the post-war boom must be an identification of those factors which generated the supergrowth of the high-productivity branches of manufacturing industry. These "engines of growth" of the West European economy were highly energy-intensive. But their expansion was not threatened by any energy-supply constraint. Energy markets were becoming increasingly competitive from the late 1950s. Substitution away from traditional, solid fuels brought advantages. It offered resource-savings not only because the real price of oil and natural gas was falling, but also because use of the new fuels was more efficient in calorific terms and brought about reductions in the requirements of labour and capital. Finally the thesis that the increased flexibility and lower cost of energy could promote imaginative technological innovations was found to be sustainable in certain, selected cases, where evidence exists of links between interfuel substitution and significant technical changes.

[55] B. Booth, M.R. Cowan & A.G. Wilson, "Effective Energy Use for Industrial Development", in Eleventh *WEC* Proceedings, Munich, 1980, I-B, pp. 366-7.